Sample Preparation Laboratory Teleoperations
Senior Design Project
(SPLT)

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EXECUTIVE SUMMARY

The Material Fuels Complex (MFC) at the Idaho National Laboratory (INL) is a cutting-edge research center with capabilities for nuclear energy research that are non-existent in other laboratories. Since 1975, microstructural research at a number of MFC's sample examination facilities has contributed on an international level to many nuclear energy advances. In August of 2012, INL completed its newest nuclear facility, the Irradiated Materials Characterization Laboratory (IMCL). This facility provides MFC with key capabilities for sample preparation including shielded hot cells, glove box and hood, mechanical properties test equipment, and several specialized examination instruments. However soon after its completion, the need for a supplemental facility to handle only beta/gamma emitting materials (non-fuels) was realized.

The conceptual design process for the new Sample Preparation Laboratory (SPL) has presented INL with the opportunity to incorporate new technologies into existing operations. As part of the mission need, SPL shall include post-irradiation examination capabilities using an X-Ray Diffraction Instrument (XRD), Electron Probe Micro Analyzer (EPMA), Plasma Focused Ion Beam (PFIB), and Scanning Electron Microscope (SEM). Because of serious health risks associated with radiation, it is necessary to place these instruments in a hot cell environment for emission containment. Most sample preparation and examination in a hot cell is currently performed using master-slave manipulators. These instruments are large, expensive, and require specialized training. Therefore, INL has to investigate new, less expensive, space-saving, and tele-operational technologies to replace the master-slave system.

The ISU Sample Preparation Laboratory Team (SPLT) has been asked to assist INL in developing the capability to load and unload metallurgical mounts containing beta-gamma emitting material from a transport system to examination equipment remotely in their new SPL facility. The SPL will need a tele-operational system capable of loading and unloading 1.97-inch diameter by 1-inch-thick metallurgical mounts to and from instrumentation; therefore, the SPLT team will be responsible for creating a system that will perform the task of removing the metallurgical mounts from canisters and then placing them in the highly sensitive and expensive instrumentation. Additionally, this objective was to be met given specifications such as accuracy, repeatability, safety, cost, and complexity.

In order to best satisfy this project scope, SPLT collaborated on 7 possible methods. These concepts included: a robotic arm, armor suit, robotic rover, crane/claw, conveyor belt/chute, and a heli-quad copter. The seventh concept was chosen to be the existing

master slave system for the sole purpose of moving it forward into the decision making process for comparison. The SPLT team used a traditional design process and decision matrix to collaborate on a final system concept. Ultimately, a robotic arm was chosen for further development.

The choice of robotic arm was based many factors and considerations such as degrees of freedom, reach, payload, programmability, and cost. Availability was also a main concern as the team only had 5 months to provide INL with their deliverable. After conducting a complete product study for various options currently on the market, the team presented INL with their decision to use a UR-5 from Universal Robots. An accompanying gripper was also selected based on degrees of freedom, payload, and maneuverability. When coupled with a highly sophisticated vision and sensory system, the UR-5 was believed to provide the most efficient solution to the project need.

Once the decision to use the UR-5 was made, the team then designated specific areas of concentration to each member so that the system could be quickly integrated. Jerron Berrett was responsible for decisions involving system kinematics and robotic maneuverability. Cody Race worked closely with the project mentor in choosing the best vision system to use in this application. Sage Thibodeau brought the entire system together using his knowledge of electronics and robotic sensory. And Larinda Nichols was in charge of making sure that all hardware and materials chosen for use in the radioactive cell would be evaluated for interference or possible radioactive degradation. The team also worked closely together to provide recommendations and solutions to several other issues that came to light as the system progressed. Many of these solutions were in answer to the off-normal, dropped sample situation and included the development of a sample tray and enclosure system.

Overall, the team was highly successful in meeting the requirements and specifications given to them as part of this project. These are summarized below.

Accuracy
The system must place the sample within a 0.01 inch radius from a desired location.

- ✓ The UR-5 has an accuracy of 0.004 inches.

Repeatability
The system must meet the accuracy specification 99.99% of the time.

- ✓ The UR-5 has a repeatability of 100%.

Radiological Environment

Equipment must be able to withstand up to 1 Curie Cobalt-60 exposure.

- ✓ Material degradation from Co-60 beta and gamma radiation was found to be negligible for a minimum of 20 years, even under constant exposure.

Radiological Safety

Personnel shall not be physically present in the cell during operation.

- ✓ The vision system allows the operator to perform all tasks and processes from outside of the instrument cell.

Overall Cost of Project

Must meet a budget of $50,000.

- ✓ The initial budget of $50,000 was exceeded as a result of an increase in project scope. A new budget of $55,000 was set in March of 2016, of which only $52,400 was used.

Complexity

Project to be completed in 9 months.

- ✓ The system will be complete and deliverable by May 5, 2016.

In summary, the final autonomous system deliverable to the INL for their SPL facility consists of a fully programed UR-5 robotic arm and 2 Rvision SEE HP cameras. These components have been installed in a complete instrument cell mock-up and a final program was created to demonstrate their individual functions. To satisfy the requirement that the system continue to be fully functionable in the off-normal, dropped sample situation, a Cognex In-Sight Micro 1100 machine vision camera and PIR motion sensors have also been included. These components would be used to manually locate the sample should it ever leave the robot gripper before reaching its destination. An aluminum tray and various enclosure options to keep the sample within reach of the robot at all times are also included in this report. Furthermore, an additional safety redundancy was incorporated. Two Elmo 3-D stereovision cameras and Wildshot 100 Pan Tilt unit ensures that the sample is always accessible to the operator even in the case of machine vision failure. These components have all been installed, tested, and proven to adequately provide the INL with a complete system for their remote sample transfer needs.

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INTRODUCTION

Background Information

Idaho National Laboratories (INL) currently has a facility known as the Hot Fuel Examination Facility (HFEF) that uses hot cells to do post-irradiation examination (PIE). Hot cells are shielded nuclear radiation containment chambers. At INL the hot cells are filled with argon and is a closed containment area. It was built in 1975 and no human has entered the hot cells since then. The HFEF has the capabilities to do non-destructive examination of irradiated samples as well as destructive testing. The hot cell is surrounded by 6 ft. of concrete to keep radiation in. Manipulating samples is done by an operator using manipulation arms known as master slave manipulators. The manipulators act as a robotic extension of the operator's hand and works by mechanical means. A 6 ft. thick, oil infused window is what the operator looks through to see what they are doing. Operating the master slave manipulator is very strenuous on the operators' arms and wrists, also looking through the window offers a distorted depth-of-field view. INL is in the process of creating a new facility that will be able to do the destructive tests in a less radioactive environment, with less physical demands needed by an operator. This facility is the Sample Preparation Laboratory.

The Sample Preparation Laboratory (SPL) at INL is a facility that will provide radioactive sample preparation including, micro- and nano- scale examination equipment as well as equipment for evaluating mechanical properties and mechanical failure modes. The facility will improve PIE currently being done at HFEF and sample quality. The SPL is a critical step in establishing and sustaining pre-eminent advanced PIE capabilities that are required to improve understanding and performance of existing nuclear reactors/ fuels and future generation.

The SPL will be composed of 4 instrumentation cells. Each cell will contain one of the following instruments: X-Ray Diffraction Instrument (XRD), Electron Probe Micro Analyzer (EPMA), Plasma Focused Ion Beam (PFIB) and Scanning Electron Microscope (SEM). Preparation of each sample will be done in a separate preparation line by a researcher. The sample will then travel in a Rabbit (pneumatic canister) through a pneumatic transfer system to the specified examination instrumentation cell. Once it reaches the room it will need to be placed into the examination equipment.

Description of Problem

INL needs the capability to load and unload metallurgical mounts containing beta-gamma emitting material from a transport system to examination equipment remotely in their new SPL facility.

Project Need

INL's SPL is in need of a tele-operational system capable of loading and unloading 1.97-inch diameter by 1-inch-thick metallurgical mounts to and from instrumentation. The goal for this project is to create a system that will perform the tasks of removing the metallurgical mounts from canisters and then placing them in the highly sensitive and expensive instrumentation.

DISCUSSION

Objective

The objective for this design is to investigate the integration of kinematics, electronics, materials science, and radiation physics for the design of a system for use in a nuclear hot cell environment. By meeting this objective, the design will improve current conditions for operators working in these conditions as well as the procedures for these types of environments. It will also provide INL a glimpse of current technological advances that could improve the processing of material for INL as well as other nuclear research facilities across the country.

Specifications

For this design there is a set of constraints that the system design must work around or integrate to meet the needs of INL. Designing the system to meet all the constraints and specifications, the final design for the system will improve efficiency and accuracy of the process, eliminate the need for expensive shielded windows, reduce in-cell lighting requirements, and improve the ergonomic conditions of operators compared to the existing technology used currently. The main requirement is that the system be able to remove and return a sample from a transfer system as well as an instrument. The next main constraint is that the operators be able to look inside the room without being in the room, in other words have an integrated vision system to be able to see all areas of the room. The system must have accuracy and repeatability, meaning that it has to be able to repeat the process over and over again with very minimal deviation from the programmed and desired operation. The system being placed in a hot cell environment must be able to withstand radiation that could be present at any time in the room. A complete list of the specifications can be seen below:

- Remove and return the sample to the transfer system
- Remove and return the sample to the Rabbit
- Remove and return the sample to the instruments
- See inside the room without human being in the room
- Pick up a dropped sample without the need of a human in the room
- System places sample within a .5-inch radius from desired location
- System meets the accuracy specification 99% of the time
- Operated by left and right handed operators
- Equipment must withstand a total absorbed dose of 1×10^6 Rad
- Rounded corners when edges are less than 90 degrees
- Physically be able to sense obstacles and shut down during maintenance
- Personnel should not be in the same room while robot is in operation
- 10-year lifecycle
- Be able to remove and replace components within 24 hours
- Physically maneuvers and reacts to dropped samples within 10.5' x 8' area
- Does not exceed a cost of $50,000
- Time to completion takes less than 9 months

Technical Information

PRELIMINARY DESIGN IDEAS

In order to come up with a system that would best solve the problem statement, the team brainstormed ideas that could potentially meet the requirements. At this point in the design process, all ideas were kept and considered until quantitative standards were set that could single out the best options. The team came up with seven ideas to be considered.

The first idea considered was the master slave manipulator. This is a mechanical arm currently used in most hot cells today. An operator has a manual control apparatus that allows them to maneuver the mechanical arms in the hot cell from a safe location. The operator views into the hot cell through a 4-ft-thick oil-filled glass window that protects them from radiation exposure. The master slave manipulators were considered because they are a tried and true method that has been used in the industry for many years and are quite capable in carrying out most tasks required in the hot cell. However, the mechanical arm and the window in which the operator views their work through in the hot cell are extremely expensive and can be strenuous on the operator because they must be on their feet while operating the master slave manipulator and they must sometimes contort their body and arms in awkward ways to get the mechanical arm to carry out their task.

The second idea was a robotic arm placed in the hot cell. The robotic arm would be anchored to either the floor or ceiling so that the arm could retrieve and deliver the radioactive sample to both the pneumatic transfer system and the experimental instruments. The benefits of the robotic arm are that robotic arms are cheaper when compared to something like the master slave manipulator arm and there is the option of either having the robotic arm be operated manually by the operator, or the robotic arm can be programmed to carry out its various tasks without any operator input. The robotic arm also has the potential to eliminate the expensive oil-filled glass windows currently used and instead rely on cameras in the hot cell to view activity. The drawback to the robotic arm is that if it is bolted to the floor and happens to accidentally drop the sample it is carrying, then some sort of method would need to be designed to prevent the sample from rolling or dropping to an unreachable part of the room.

The third idea was to send a person wearing an armored suit into the hot cell to place the samples into the experimental instrumentation. The armored suit would be shielded so as to protect the wearer from being exposed to any harmful radiation. This design idea would eliminate any accuracy or precision errors that may be present with the other systems and could also eliminate the need for the thick oil-filled glass window. However, the technology and materials required to build such an armored suit are still quite new and expensive. The suit could also prove to be quite bulky and hard to maneuver in a small space in the hot cell.

The robotic rover concept basically takes the robotic arm concept and puts it on wheels. The rover would be able to maneuver throughout the entire hot cell and be automated or tele-operated. The potential for dropped samples, like in the case robotic arm concept, would no longer be a problem because the rover would be able to reach the dropped sample anywhere in the room. However, the ability to move the robotic arm throughout the room would come at a higher cost than a robotic arm that is simply fixed in place. The rover also brings a higher level of complexity when compared to something like the robotic arm concept.

The fifth idea was a maneuverable overhead crane or claw. The track system would be located on the ceiling so that the claw could maneuver around the hot cell without being impeded by any obstacles. The claw would be capable of lowering to the pneumatic transfer system and instruments, or, if there was a dropped sample, the claw could reach all the way down to the floor. A problem with this design is that some of the experimental equipment that the samples need to be placed into cannot be loaded from the top. Some solution would need to be found to allow the claw to load the instruments from the sides.

A conveyor belt or chute was also considered as a potential system to load the samples into the experimental instruments. Chutes and conveyor belts are commonly used in factories to transport large quantities of material from one location to another. While the system would be able to transport many samples from the pneumatic transfer system to the instruments, for the purposes of this project only one sample would need to be transported at any given time. The conveyor belt and chute may also lack the accuracy and precision required to deliver and load the samples into the instruments.

The final idea considered was a heli-quad copter. The quad copter would be equipped with some sort of claw arm to be able to pick up the sample and place it into the instruments. The quad copter would be capable of accessing most of the hot cell and be either tele-operated or autonomous. The drawbacks with using the quad copter are that a battery would be required and would need to be charged constantly. There would also be a potential for the quad copter crashing in the hot cell and damaging expensive equipment or itself.

After selecting some preliminary ideas to be considered, they were compared using quantitative standards in a decision matrix.

DECISION MATRIX

Paring down the original seven items into three concepts was done using a decision matrix. Specifications for the project were first determined based on engineering experience and customer requests. Weights were then given to each specification based on their importance to the customer as well as the over-all project. A 1-5 scale was used in the weighting of each specification. A ranking of 1 was used for optional specifications that had little effect on the project. A ranking of 3 was used for desired specifications, which meant that the customer desired them and should be implemented on the final concept. A ranking of 5 was used for mandatory specifications. If these specifications were not in the final concept, the project would not work for the customer's needs. If the specification was in between these weights, it was given a 2 or 4 depending on importance. Next, the concepts were compared side by side with another 0-5 scale. A score of a 0 meant that it did not meet the specification at all, a score of a 5 meant that it could fully meet the specification. Final scores were determined by multiplying the weighted number by the score given for each specification, then these values were added together for each individual concept (see Table 1).

TABLE 1: Table of Final Matrix Scores

Concept	Score
Master Slave Manipulator	217
Armor Suit	212
Robotic Arm	253
Robotic Rover	247
Chute/Conveyor Belt	143
Crane/ Claw	216
Heli-Quad Copter	198

CHOICE FOR FINAL DESIGN

A decision matrix was used to determine which of the above listed concepts would be carried forth in the design process (see Appendix A). The decision matrix was used to illustrate the weighted score of each concept as they met the project specifications and requirements. The results indicated that the robotic arm best met all requirements of the project; therefore, it was chosen for final design.

PROCEDURAL FLOW CHART

Two flow charts were also created to get a visual perspective of each step required in the robotic procedure. One flow chart is for the incoming procedure (Appendix B) and the other is of the outgoing procedure (Appendix C). The flow charts allowed the team to determine the best way to complete each required step in the sample transfer process. Concept ideas for each step were then collaborated upon, and the best choice was determined.

Incoming Procedure. The incoming procedure happens when the sample has been prepared by the researcher and is sent into the instrumentation cell. The transfer system will be used to send the sample to the cell. While this happens, the robotic arm or the operator, by automatic means, will open the instrumentation equipment to ensure it is ready to receive the sample. The operator, through visual means, or the robot, by sensors, will know that the canister from the pneumatic transfer system has arrived. Next, the operator or robot will open the transfer system to receive the canister. The robot will then grab the canister from the pneumatic transfer system.

At this point while moving the canister to the opening tray the sample could be dropped or make it to the tray. If the sample is dropped the robot or operator will sense where the dropped sample is by sensors (robot) or cameras (operator). The robot will then grab the sample and orient it and move the sample to the tray as originally planned. The robot will then proceed to open the canister using an x-y plane flip top lid. The robot will then proceed to dump out or remove the Rabbit from the container. The Rabbit could accidentally be dropped at this time. If this happens, the same dropped sample procedure as above will commence. Once returned or if not dropped, the next step is opening the Rabbit, which will be done by the robot. The robot or operator will sense that the sample is indeed in the Rabbit. The robot will then retrieve the sample. At this step it could be dropped or moved to the instrument opening. When it reaches the instrument opening the sample is oriented either by robot control or operator control. The sample, once oriented, will then be placed in the instrument. The door will be closed by either the operator or robot, and the experiment will be programmed to run.

Outgoing Procedure. The outgoing procedure is much like the incoming procedure, but in the opposite order. When the experiment finishes, the researcher or operator will ensure that the experiment is truly done and that all data is gathered. The operator or robot will open the transfer system and ensure there is nothing blocking that would cause problems when sending back to the preparation line. The operator will put the robot into retrieve mode. The robot or operator will open the tray to the instrumentation. The robot will then proceed to grab the sample. The sample will be moved to the tray where the Rabbit and canister are from the incoming procedure. The sample could be dropped as well before making it to the tray, which the dropped procedure will then be used to get the sample to the tray.

Once returned to the tray, the robot or the operator will orient the sample to the correct orientation to be placed in the Rabbit. The Rabbit will then be oriented for placement in the canister. At any of these two previous steps the sample could be dropped and the dropped sample procedure would be used if this happened. Once the canister has been closed, it will be oriented to the position needed to place in the pneumatic transfer system. At this point the sample could be dropped in which case the dropped sample procedure would be followed to return it to the correct step in the process. The canister will then be placed in the transfer system. The robot or the operator will close the transfer system. The operator will then send the canister back to the preparation lab.

Both procedures showed how big of an impact the dropped sample would have on the entire procedure, both in time and efficiency. This part of the design will be the focus of the design. All other steps can be completed no matter the configuration of the dropped sample design.

System Design

Once the robotic system was identified as the optimal solution to the project need, the next course of action was to separate the design process into areas of focus. These are as follows:

1. Kinematics – Ensure the robot meets the mobility needs of the project.
2. Mechanical Design – Equipment necessary for robot to perform each task.
3. Materials – Materials required and their behavior in radioactive environments.
4. Vision System – Robot will require advanced optical systems for teleoperation.
5. Electronics – Programming and sensors are integral to accomplish procedure.

<u>KINEMATICS</u>

Requirements and Assumptions

The project requirements for selecting the robotic arm were as follows:

a. Must be commercially available
b. Size of robotic arm (robot must be capable of performing tasks without causing interference to equipment within its reach)
c. Axes of motion (degrees of freedom) which addresses flexibility to perform work
d. Accuracy and repeatability
e. Placement relative to room size, pneumatic transfer system, and instrument (with recommended clearances around instrument)
f. Ability to remotely open/close pneumatic sample carriers
g. Ability to retrieve dropped sample
h. Purchase and maintenance cost

In addition to the project requirements listed above, the following assumptions were also made as part of the decision making process:

a. Payload for this application is negligible
b. All four instrumentation cells will employ the same system
c. Robotic arm may be mounted in a stationary position or on a moveable track.

d. Robotic equipment considered for other non-instrument areas (such as the Materials Properties Test Cell) of SPL are independent of this study, and
e. Processes are programmed. Exceptions may occur where commercially provided teleoperation features of robot may be used for robot program teaching or picking up of dropped sample also known as the off-normal situation.

Robotic Arm Choice

A variety of robotic arms are currently available on the market however, the specific nature of this task has led the team to a company called Universal Robots of Denmark (they have significant distribution in the United States). Reasons for this decision of robotic arm include accuracy, reliability, cost, ease of programming and the radius at which it can reach. Universal Robots robotic arms also have 360˚ motion at each of the joints which other robotic arms did not. To go along with this motion at the joints Universal Robots robotic arms also has six degrees of freedom. The degrees of freedom needed in the robotic arm was important for this project, because if it does not have a sufficient amount of degrees of freedom the robotic arm would not be able to do the task it needs to perform.

Each joint of the robotic arm is a revolute joint having one degree of freedom. The number of joints on the Universal Robotics robotic arm is six, totaling up to six degrees of freedom. The minimum degrees of freedom that would be needed to complete the tasks was found to be five with the help of SolidWorks. The way that SolidWorks helped in determining the minimum degrees of freedom was to take out one of the joints on the top end of the robot arm (Appendix D). In Appendix E, it can be seen what the arm looks like with all of its joints. The reason that SolidWorks was chosen for this was because it would allow to move the robotic arm in any position to ensure that the robotic arm would be able to perform the task needed. With five degrees of freedom the robotic arm was still able to perform the tasks needed (Appendix F). This procedure was also done with the six degrees of freedom robotic arm to show it working as well (Appendix G). If anymore joints are taken out reducing the degrees of freedom the robotic arm would not be able to perform the task needed. The reason that no other joints can be taken out is because it limits the motion of the arm. With five degrees of freedom it is still able to move in the orientations needed.

As soon as the degrees of freedom drop below five the arm loses the ability to move in the positions it would have to be in to complete the tasks. This was done by starting from the top of the arm and working down because some of the joins were more important than others. This is because there were some joints that are more important than others. The robot arm needed to be able to move at its base in order to get other joints around. Then the next joint needed to be able to move to give it motion in the x-plane. Then the next joint was to give it more motion in the x-plane and in the y-plane. At the top of the arm there is three joints. Each of these joints give the arm the ability to orient the arm into many positions. If two of these are removed, it will lose motion to do this. Even though it would still have one joint for motion at this point in the arm it would not have the ability to change the orientation of that joint. This would be needed to be able to perform the task of placing an object in areas with precision.

Universal Robots also allow easy integration of a customized, versatile two-finger gripper, supplied by the company Robotiq. The gripper adds extra reach of up to six inches and can handle loads of up to 11 lbs. Universal Robots offers a line of robotic arms with proportional specifications based upon reach and payload. The table below shows all of the robotic arms that Universal Robots offers.

TABLE 2: Universal Robot Product Line

MODEL	PAYLOAD	WEIGHT	REACH	FOOTPRINT	COST
UR-3	6.6 lbs.	24.3 lbs.	19.7 in	4.6 in	$23,000
UR-5	11 lbs.	40.6 lbs.	33.5 in	5.9 in	$35,000
UR-10	22 lbs.	63.7 lbs.	51.2 in	7.5 in	$45,000

The benefits of using a UR-3 model for this application include less initial expense and smaller footprint. However, the UR-3 does not provide adequate reach for loading and unloading samples. It also does not allow for a large enough clearance space for the necessary instrumentation access for maintenance.

The UR-5, sample room layout in Appendix H, provides a larger reach, but is compact enough to allow for potentially more safety features such as a full enclosure for an off-normal situation. Additionally, the payload is almost double that of the UR-3. The UR-10, sample room layout in Appendix I, is likewise a choice for its longer reach and higher payload which allows for future capabilities should the need arise. It is understood, however, that this additional reach could prove problematic for an off-normal situation during transfer. This is due to the larger area that the sample could potentially be dropped.

All models provide the accuracy and repeatability required for the application; therefore, the final decision is based on robot reach and payload, taking into consideration area to drop the sample and instrument access. As a result, the team constructed a simple and inexpensive three-dimensional mock-up, as seen in Appendix J, of an instrumentation cell to compare the performance of each robot relative to the given workspace. This mock-up provided a life like, realistic visual for the team to determine the best position for the instrumentation (PFIB in this case) and the other components needed. A model of the UR-3, UR-5 and UR-10 were inexpensively constructed to be used in the mock-up of the instrumentation cell. These were used to determine the relative positions in the x-y-z planes that would allow for the proper procedure to be done. This would also show, if any, possible limits of each robotic arm. The UR-5 and UR-10 were deemed sufficient for further exploration. Using SolidWorks, a 3-D model was prepared to identify the best possible solution with both robots placed where they would be placed in the mock up (Appendix H-I).

After simulating the maneuverability of the UR-5 and UR-10 in a 3D mockup of the sample cell, weighing the benefits, and weaknesses of both robots the recommendation would be to use the UR-5 in the Sample Preparation Laboratory instrumentation cells. The UR-5 is commercially available. The size of the robotic arm is capable of performing tasks without causing interference to the equipment or maintenance to the equipment. It can move in all desired positions due to its six degrees of freedom. The UR-5 can be placed in such a way that it meets the equipment space requirements based on the recommended maintenance space from the PFIB manual and requirements discussed with Dean Blanton, (INL SEM/FIB Specialist at MFC) while looking at the PFIB. A benefit discussed earlier that the UR-5 has over the UR-10 is a potential for total enclosure that would allow complete assurance that the sample will always be able to be obtained remotely or tele-operated by the robotic arm. The UR-5 and UR-10 differ when it comes to cost and the radius of reach. The UR-5 has a cost of $35,000, the UR-10 costs $45,000, which could potentially bring a savings of around $40,000 if UR-5's are used in the three neighboring cells running similar operations. The smaller reach of the UR-5 decreases the radius for an off-normal situation, but is still capable of maintaining adequate distance between the instrumentation and pneumatic transfer station for maintenance. The smaller radius in which the sample can be dropped is very beneficial in making sure the sample does not get lost in the cell, as well as keeping the dropped sample recovery system simple and compact. A downside to UR-5 is the potential for longer maintenance time removing safety barriers.

Suggested Alternative

The UR-10 is considered a viable option for the SPL instrumentation cells because it can also carry out the same tasks as the UR-5, although its size and reach are larger than required for this application. The UR-10 is less desired when considering cost and the potential for a dropped sample. Despite the UR-10 having a longer reach, which could allow for more space for maintenance and possible future applications, it also increases the radius for the off-normal dropped sample could be lost in the cell. The ability to be fully enclosed is also not reasonable due to the size of the arm. The benefit of having a larger reach does not counteract the danger of having a larger radius for a dropped sample. The attachable gripper is also only rated for 11 lbs while the UR-10 is rated for 22 lbs, so the only benefit gained from the UR-10 would be the reach. For this application payload is assumed to be negligible. The UR-5 is deemed to be a better option than the UR-10.

Robot Reach

The next step after selecting the robotic arm was finding out where it could reach. The reason for this was to be able to determine where the robotic arm could recover a dropped sample. Also we needed the reach to determine the most beneficial position for the robot to be able to complete its tasks. An Auto cad drawing of the reach of the UR-5 robot can be seen in Appendix K. This cad drawing is a drawing of the room that is being worked with for this project. The drawing shows all of the walls as well as the instrumentation that is being used, this is the box that is on the left in the drawing. The drawing also shows where everything would be placed in the cell. The robot was placed in the best possible position that would allow the robotic arm to complete the task and still reach where it would need to. To expand on the drawing, the inner green circle was where just the robotic arm could reach. Then a Robotiq gripper was added to the robot arm extending the reach of the arm by six inches. This is indicated by outer green circle. Anywhere that has red hash marks indicates where the robotic arm cannot reach. Likewise, anywhere that has green hash marks is where the robotic arm can reach. Where the green and red hash marks come together in the insemination equipment indicates the robotic arm can reach there but it is limited. This area has a tray that is raised and has an area underneath that the sample has a chance of going if it is dropped. Also in the picture is the transfer table. This table is where the sample would be coming into the room and where it would be oriented for placement in the instrumentation equipment. Things that would be on this table include a transfer system, a carrier holder, a tray to place the sample on, and articulation tools. The carrier holder and articulation tools will be expanded upon later in this report. The drawing of the reach was needed to know where to place the things listed above. This will ensure that the robotic arm will be able to reach the things it needs to reach.

MECHANICAL DESIGN

A carrier will be unloaded from the transfer system by the robotic arm. The carrier will possess another carrier which houses the sample. A carrier holder was designed in order to hold each carrier separately while not in use. The design of the carrier holder is a simple design consisting of two circles placed a distance apart from one another. Each circle has the dimensions greater than the outside diameter of the carriers that will be made. An O-ring will be cut out so that it has three tabs that go in the holes that are in the carrier holder. The O-rings will help provide friction so that the carrier holder will hold the carrier better. This is for when the robotic arm needs to open the carriers. A drawing of the part can be seen in the Appendix L. This part was printed using a 3D printer that were provided by ISU.

The carrier holder had to be printed in two part because it was over the size limit of the printers. For this reason, the two parts were glued together. The assembled part was bolted to the table so that it was perpendicular with the table. The end with the larger circle was placed towards the wall and the smaller end towards the robot arm. This placement of the carrier was done so because of the procedure of the robot arm. When the carrier comes into the transfer station it is in the larger carrier. Once the robot gets the smaller carrier out of the larger one, it can place larger one in the carrier holder in the back so it is out of the way. Hand calculations were done for this to show that it would not fail if the robot were to hit the side of the carrier holder (Appendix M). An assumed force was chosen for these calculations. The force chosen should be higher than what the robot would be able to apply. The robot has a safety feature programed into it so that if the robot reaches a force of this value it will shut itself off.

Articulation tools for the robotic arm were also designed to be used in case a sample is dropped and out of the reach of the robot. There were two tools that were designed to be used with the robotic arm. The first tool is a J-hook a drawing of this tool can be seen in Appendix N. This is a hook tool that would be able to go around the sample and pull it to a spot that the robot can acquire the sample. The places that this would be used are underneath of the instrumentation equipment or on top of the equipment where the robot would not be able to reach. The J-hook has to have an offset handle designed into it. This is to keep the gripper that is attached to the robot up off of the instrumentation equipment. If this offset was not high enough, then the gripper would drag across the equipment. This could cause stresses where the gripper and robot arm are attached that can be avoided. The J-hook will attach to this offset where a slot is in the tool. This slot has been designed to allow the gripper end to go into the end of the tool. Once the gripper end is in the tool it is able to grasp the tool to be able to carry the tool wherever it needs to be able to obtain the sample.

The next tool that was designed was tongs. For this tool a set of tongs was bought from McMaster Carr. These tongs will have to be equipped with the same offset but with some changes see Appendix O-P for the drawings. The tongs will have to have two pieces in order to work the tongs. In order to attach the tongs to the offset handles to the tongs, a slot was made for the ends of the tongs handles to go into. With the handles of the tongs in the offset handles, two set screws will be tightened on each side to hold the tongs in place. The holes that are shown in the drawings for the set screws are just for indication of where they will be placed. On the end of the offsets where the gripper attaches, there will be a spring screw that will hold the offsets onto the gripper. The spring screw has a ball with a spring behind the ball to allow the ball to be pushed out. The screw will be placed into the side of the offset handle in a specific location. As the gripper goes into the slot for the gripper end on the offset handle the spring ball will go into a place on the outside of the gripper. This spot is already machined into the gripper and will be useful for this. This will allow the tongs to stay on the gripper and still be functional

One modification that will be made to the tongs is to add an elastic band around the outside of them. This will make it so that the tongs will always be in the closed position at all times. This is desired so that if the tongs should fall off of the robot gripper then the sample would still be held in the tongs. The tongs would be used in a case where the J-hook would not be able to get around the sample or if the user sees fit that it would be easier to grab the sample. The J-hook as well as the tong offset handles are 3-D printed for the use of demonstration purposes. A recommendation would be to have the tools made in a machine shop for better durability.

The robots horizontal position needed to be determined; this meant that the stand had to be able to be adjustable in the horizontal direction. Accomplishing this was done by designing a stand with an inner slide that was separate from the outer slide. The stand not only needed to be adjustable but had to be level, sturdy and able to withstand the various forces and stresses that the robotic arm might put on it throughout its task movements. The design of the stand included a larger diameter outer pipe and a smaller diameter inner pipe. The larger diameter pipe was welded to a base plate. The smaller diameter pipe was welded with a smaller plate on top. The larger diameter pipe had two holes drilled into it at 90˚ angles from each other with nuts welded over the holes. Bolts were then used to be able to create a clamping force on the inner piping to hold it at the necessary height. Appendix R and S show the drawing and design of the stand as well as the calculated forces and factors of safety for the stand components and bolts to hold the stand to the floor and the robot to the stand.

MATERIALS

Materials used in the design of the instrument cell include stainless steel, aluminum, and Plexiglas. The cell itself will not be inert, but there is no concern of oxidation since humidity and temperature will be kept at optimal levels for the examination equipment.

The instrument cells in the SPL facility will examine samples emitting both beta and gamma radiation. Any alpha contamination will be removed from incoming material in the sample preparation line decontamination cell before entering the remaining areas of the facility. The purpose of using teleoperations to handle these samples remotely is the focus of this project; therefore, only a radiation analysis on the materials surrounding the instruments will be necessary. No direct human interaction with the samples is permitted.

A 1 Curie Cobalt-60 source was specified as the standard for determining radiological effects within the cell due to its dual emission of both gamma (γ) and beta (β) rays. For every decay of Cobalt-60 to Nickel-60, approximately 1.89 MeV β^- and 2.5 MeV γ will be emitted. Both emissions are forms of ionizing radiation, which only interacts with the electrons surrounding the nucleus of an atom. Beta radiation and low energy gamma radiation (under 10 MeV) will not activate the materials they come in contact with.

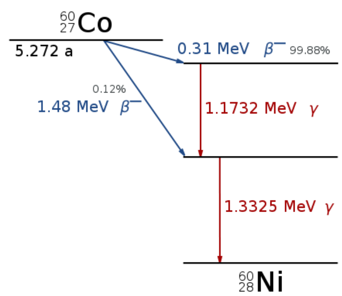


FIGURE 1: Decay Scheme of Cobalt-60
(National Nuclear Data Center, Brookhaven National Laboratory)

In most inorganic substances, ionizing radiation causes electrons to migrate out of their original position. Ejection of electrons from the material subsequently decreases its resistivity, increases its conductivity, and may even cause disruption in its native lattice structure. Polymers have characteristic bonds consisting of long chains of molecules. If any of these bonds are broken and this chain rearranges, the polymer may experience physical changes in hardness, flexibility, and appearance.

The material used for the proposed robot enclosure is plexiglass, a type of polymer. However, the behavior of Plexiglas in a radiological environment has been previously observed and well documented by CANDU Technology, and the absorbed dose required for noticeable deterioration has been found to be approximately 20 MRad (see Figure 2). It would take over two decades of constant exposure from a Cobalt-60 source at a distance of only 1 foot to achieve this amount of absorbed dose (see Appendix Q for details on this calculation). Therefore, the effects of radiation on any plexiglass used in the instrument cell were deemed insignificant.

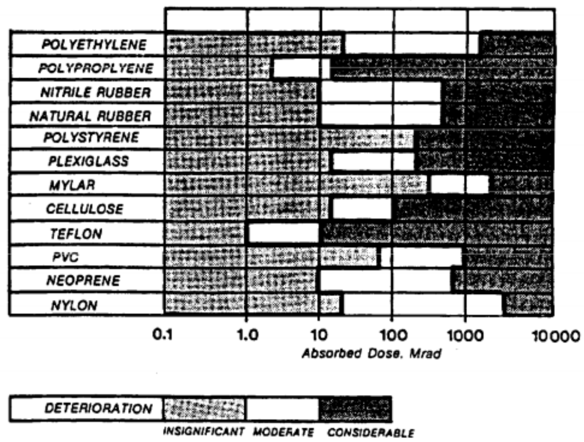


FIGURE 2: Effects of Radiation on Various Polymers
(CANTEACH Project, CANDU Technology)

Main electronic components for the robot will remain outside of the instrument cell. Any necessary cabling to connect the robot to these components can be commercial grade. Most commercially available cables will not show significant degradation up to a total dose of 1MGy [Houssay]. If degradation is somehow suspected, it is more cost effective to remove these cables from service. Hardening is costly and unnecessary.

Other inorganic substances used in each instrument cell include aluminum and stainless steel. But metals do not behave like polymers in the presence of low energy ionizing radiation. They do not degrade or experience any significant changes in lattice structure. This is due to the fact that electrons in metals are very mobile and move easily from one position to another. Under influence, any vacancy created by the movement of an electron from its original position will be quickly filled by another electron. Consequently, any metals contained within the instrument cell will remain unharmed and non-radioactive when considering the maximum source of 1 Curie Cobalt-60.

In addition to extensive research and radiological calculations, the Idaho State University Health Physics Department was consulted on various occasions to verify the results of this study (summarized below).

- Cobalt-60 decays by both gamma and beta emissions.
- Emission of 2 gamma rays per Cobalt-60 decay, 117 MeV and 1.33 MeV, for a total energy of approximately 2.5 MeV.
- Gamma and beta emissions are both forms of ionizing radiation (IR).

- Beta radiation does not leave material radioactive.
- Low energy ionizing gamma rays (with energies is less than 10MeV) do not activate surrounding materials.
- Neutron radiation and some high energy gamma will activate metal components; however, these energies are not anticipated in SPL.
- Gamma radiation attenuation for personnel safety requires 8-inch-thick, high density steel to be used in the construction of instrument cell walls.
- Beta radiation can be attenuated by thin aluminum sheet, ranging from 60 micrometers for 0.5 MeV to 550 micrometers for 3 MeV.
- IR is a problem for most inorganic substances because it interacts with the electrons surrounding a nucleus and causes them to migrate out of position.
- Ejection of electrons from the material decreases resistivity, increases conductivity, and causes changes in lattice structure.
- Metals are an exception to this behavior
- Electrons in metals are very mobile and move easily from one position to another. Under influence, any movement of an electron from its original position can be replaced quickly with another electron. Only a short transient period exists.
- Negligible effects from IR to stainless steel or aluminum materials in cell.
- Non-metal materials (plexiglass and polypropylene plastic) may become altered as IR strips electrons and changes bonds between atoms.
- Oil is also affected by high levels of radiation. As electrons are displaced by ruptured bonds, the oil viscosity increases and lubricant flow decreases. Lubrication of bearings may be required more often.
- Special additives can also remedy this issue.
- Polymers have characteristic bonds consisting of long chains of molecules; therefore, polymers change if these bond arrangements change.
- Bonds break and reform, changing physical properties such as hardness, flexibility, and appearance (visibility).
- Plexiglass and polypropylene plastic susceptible to becoming softer and weaker.
- Radiation anticipated in instrument cells, based on 1 Curie Cobalt-60, will not have this effect, however. Absorbed dose deterioration is shown to be insignificant up to approximately 20 MRad (see Figure 2).

- Radiation hardening is of minor concern and deemed unnecessary for this application.
- It was found to be more cost effective to remove material from service when deterioration becomes considerable than to invest in radiation hardened components.
- Commercially available cables do not show significant degradation up to a total dose of 1MGy [Houssay]. But further efforts to keep radiation exposure to conservative include keeping on-board electronics to a minimum using connection wiring.

Enclosure Concepts

The accuracy and repeatability offered by the UR-5 and Robotix gripper provide reasonably high confidence that samples will not be dropped or misplaced during operation. However, the sensitive nature of radiation makes it very important to consider all possible scenerios. The machine and stereovision systems can be used to exit autonomous mode and retrieve the sample manually, but the sample must remain within reach of the robotic arm to do so. For this reason, the following enclosure concepts are recommended for further consideration and development.

The first enclosure is a small, mobile option. Rather than enclosing entire arm, instrument, and transfer table, this acrylic “glove” will keep the sample enclosed during any transfer between PFIB and table (see Figure 3). This option has the potential to eliminate the need for a larger enclosre that might hinder robotic movement or instrument access.

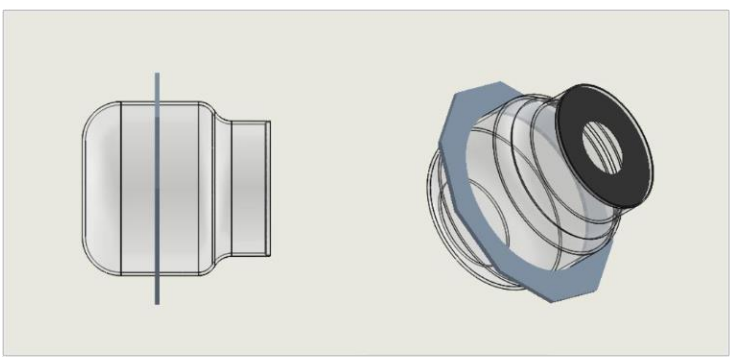
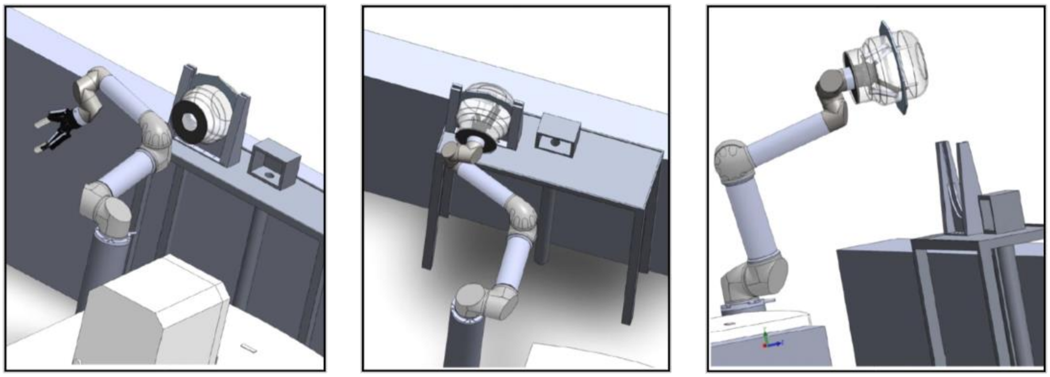


FIGURE 3: Concept 1 - Small Enclosure

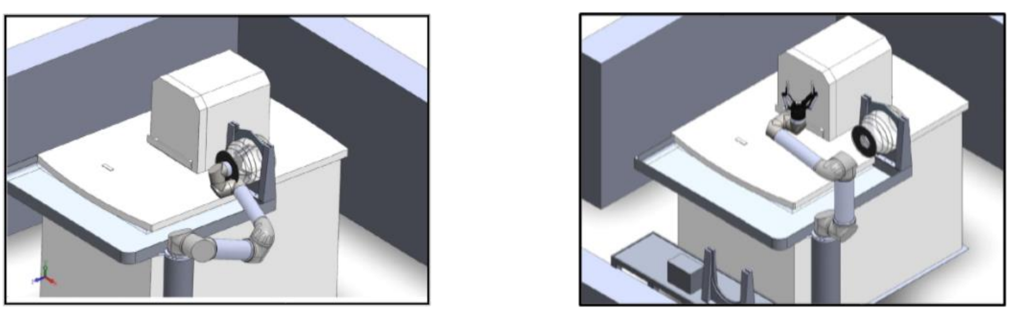
First, the robot would retrieve the sample from the incoming pneumatic system, then orient it within the Robotix gripper. The small enclosure would be docked in a custom stand located next to the carrier system on the transfer table. This stand has been specifically designed to keep the enclosure stationary, resisting the pushing and pulling action from the robotic arm, until the loaded gripper is fully inserted and the robot can lift the enclosure up and out of its station (see Figure 4).



(a) (b) (c)

FIGURE 4: Enclosure Concept 1 – Small Enclosure
(a) Docking Station (b) Gripper Inserted into Enclosure (c) Enclosure Movement

The robotic arm would then move to the second docking station on the instrument table to withdraw the gripper for sample transfer to the instrument tray (see Figure 5). This process would ensure that the sample remains fully contained at all times during transfer. Even in the unlikely event that the sample falls out of (or is dropped from) the gripper during this transfer, it will remain within the enclosure until the robot can return to the transfer table. The robot could then be used to invert the enclosure to remove the sample to the table, reload the sample into the gripper, and repeat the transfer process.

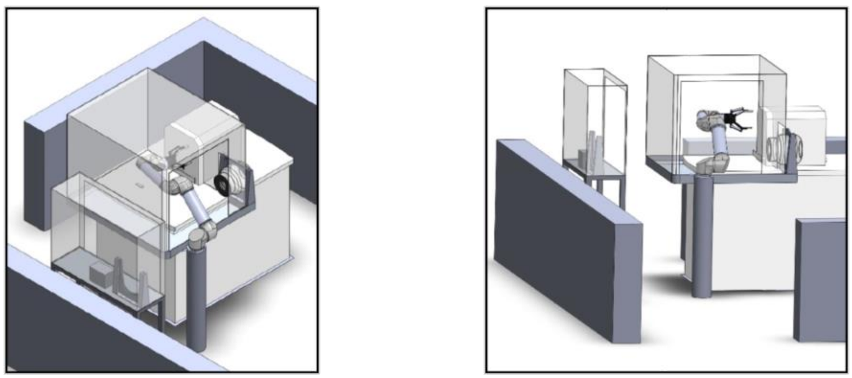


(a) (b)

FIGURE 5: Enclosure Concept 1 – Loading Gripper & Transfer
(a) Second Docking Station (b) Removal of Gripper

The enclosure has been fitted with a thick rubber gasket at the opening to reduce the possibility of separation from the robotic arm during transfer; however, it is recommended that an inclined tray be located under the entire reach of the robot to eliminate this concern.

A second option for enclosure uses acrylic to house both the transfer table and instrument tray, offering additional containment as necessary (see Figure 6). If a sample does happen to roll during gripper manipulations, the acrylic would keep it contained within the confines of these two areas. This system could be easily integrated for use with the afore mentioned smaller enclosure, or possibly only the inclined tray if desired.



(a) **(b)**

FIGURE 6: Enclosure Concept 2 - Partial Enclosure
(a) Top View (b) Side View

The final, dome enclosure is also made from formed acrylic glass. This system extends the entire reach of the robot, is used in combination with an inclined tray, and offers easy disassembly when required for instrument maintenance (see Figure 7).

(a) **(b)** **(c)**

FIGURE 7: Enclosure Concept 3 - Full Enclosure
(a) Isometric View (b) Top View (c) Side View

Although it is believed that any of these options would be viable solutions for sample enclosure, issues involving contamination and air flow within the instrument cell must also be considered. These specifics are not yet fully defined in the development of the SPL facility; therefore, the team offers these concepts for further investigation.

VISION SYSTEM

In order to ensure that the SPL instrumentation rooms did not have the expensive, distorting oil infused windows a camera vision system was needed in the instrumentation cell to ensure the operators could see what was happening within the room. The vision system is also important to allow the operator to see the position of the robot for normal and off-normal operations. Room cameras will need to be placed in the instrumentation cell. Determining the locations and how many cameras would be needed cameras were placed in various locations based on the team's ideas and thoughts. Cameras were moved around if a better position was determined. It was determined based on the tests as well as an initial layout in AutoCAD that two room cameras would be sufficient. The layout of the cameras and their views can be seen in Appendix T-U.

The robotic system will have the ability to be tele-operated for non-programmed or off normal situations such as a dropped sample. The ability for the operator to operate the robot cannot be done efficiently or effectively with only the room cameras. A camera will be used closer to the gripper of the robot to allow for the operator to see in tele-operation mode. Many problems arose with this part of the camera system. The camera needed to be able to track the end of the gripper or allow for an unobstructed view of the end of the gripper and it also had to give the operator a realistic view to make it easy to use the gripper to pick-up the sample.

In order to allow for a more realistic viewing and depth of field 3-D camera viewing systems were looked into. The problem with the 3-D system was that many involved the operator to have to wear glasses which was not desirable. One system that was looked into that did not require glasses was a Stereovision 3-D camera system. The system involved two small cameras along with a special monitor that converted the images to a more realistic view. An older model of the Stereovision system was given to us to test with our robotic system. The stereo vision was calibrated and tested compared to a regular 2-D vision set-up. Since a Stereovision system was more expensive than a regular camera system the team wanted to ensure that the benefits were noticeable and that the system would improve the overall efficiency and effectiveness of the system. The Stereovision did show improved depth of field viewing at a specific focal length that it was set at and calibrated for compared to the regular 2-D cameras. However, the down side of the Stereovision was the fact that it was only good for such a small focal range or length. Another option was looked into to help eliminate the tele-operation altogether and make the robot as autonomous as possible, this option was Machine Vision. Machine Vision is a camera system that can recognize distinct shapes and markings of objects. Using the Machine Vision connected to the robot, the system can orient the gripper on the end of the robot to pick up the sample in the correct orientation for insertion into the instrumentation every time. The met mount which comes out of the Rabbit can be shaped special so that the Machine Vision can react to the special shape and orient the gripper for grasping the sample correctly. Machine Vision can also be used for dropped sample and off normal situations. It was determined, however, based on the nature of the tasks the robotic system would be doing that both the Machine Vision and the Stereovision would be used. The decision allows repetitiveness in the event that an unforeseen off normal situation occurs that might cause the operator to go into tele-operation mode, where the Stereovision system would have to be used.

Next, the position of these systems needed to be determined to allow for best operation. The key for the camera system positions was to have it follow with the robot and be in a position where the focal length would not change much especially for the Stereovision cameras. Both cameras were decided to be placed on the robot. This would ensure that the robotic system could track with the robot without other devices. The Stereovision was originally decided to be placed at the base of the robot and be clamped so that it would rotate with the robot. However, after further testing with the programming of the robot and position of the cameras it was determined that the robotic camera system would be placed at the 3rd joint from the base. This was decided because the focal range of the robot with the camera at the base was too large for the 3-D vision to work at its best. By moving it to the farther position the overall view shrunk but the focal length would not change by much and allow the Stereovision to work at its best. A clamping system was designed to allow for this camera system to be in this position. The machine vision had to be in a place where it could distinguish between minor changes in shape or certain markings. Multiple ideas were thought of to determine the best position for this. One idea was to mount it to the transfer table where it would be stationary. Another idea was to attach it directly to the robot which is the best to make the robot as autonomous as possible and be able to react to the dropped sample.

ELECTRONICS

Autonomous Operation. The goal for using the Universal Robot arm is to design a system that is capable of operating autonomously without any input from the operator. For that to be possible, certain electrical components, sensors, and cameras must be integrated into the system in order for the robot to adapt to the changing variables in the work zone. The following sections will delve into what physical quantities need to be sensed, what approach was taken to solve this problem, and what final solution was taken to create an autonomous system.

Sensing Dropped Objects. The objective of the robotic arm is to carry a radioactive sample from a pneumatic transfer system over to a nuclear experimental instrument, load it in the instrument, and then unload it and return the sample to the transfer system when the experiment is finished. One possibility that needs to be addressed is what if the robot somehow drops the sample or knocks over another object? The system needs the capability to recover the sample or dropped object so that the experiment can commence and no human needs to enter the hot cell. For that, the robot must have some way of knowing when an object is dropped. This is where sensors come into play. There are many different types of sensors capable of measuring different quantities such as temperature, distance, sound, light, and so on. In this case, the sensor must have the ability to sense the presence of an object that was not there previously or should not be there at all. Several types of sensors were considered for this application.

Ultrasonic Sensors. These sensors work by sending out ultrasonic sound waves that bounce off objects and return to a special microphone. The sensor measures the time it takes for the waves to return and uses this to identify how far away an object is. It can "see" objects at distances between 0.8 in and 10 ft. Its limitations are that it may not sense an object if its reflective surface is at a shallow angle (less than 45 degrees). The ultrasonic sensor also only has a line of sight of about 40 degrees.

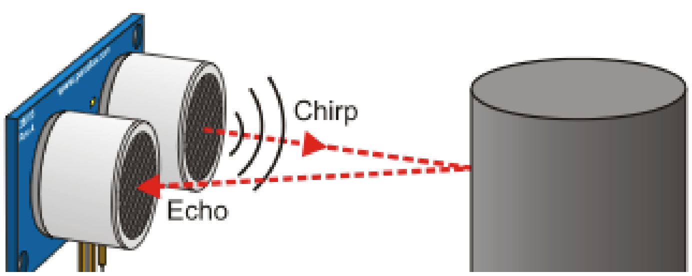


FIGURE 8: Parallax Ultrasonic Sensor
(*Ultrasonic Distance Sensor*. #28015. Parallax Inc.)

Passive Infrared Motion Sensors. These sensors are dome shaped and have honeycomb like sections inside that detect changes in infrared waves. The passive infrared sensors do not send out any infrared waves, but detect infrared waves given off by objects in their surroundings. The range of PIR motion sensors is 30 ft. with a view angle of 120 degrees. These simple sensors send either a digital HIGH signal if movement is detected or a digital LOW signal if no motion is detected.

The main factors considered when comparing these two sensors were cost, simplicity, and range. The PIR motion detector was chosen as the sensor to be used in the system because it was cheaper than the ultrasonic emitter, sent a simple HIGH or LOW signal rather than a wide analog signal, and it had more than enough range as well as a wide field of view.

FIGURE 9: Parallax PIR Motion Sensor
(*PIR Sensor*. #555-28027. Parallax Inc.)

PIR Motion Sensor Layout. A shortcoming of the PIR motion sensor is that if an object falls into the sensor's field of view, the sensor cannot give a very precise location of where the object landed. To combat this, an array of sensors surrounding the robot in a circular pattern are used with overlapping fields of view to increase the resolution of the system. Several sensor layouts were tested using AutoCAD to determine how many sensors would be reasonable. It was determined that a minimum of three sensors is needed in order to cover the entire region around the robot. However, it is desirable to have the sensor's views overlapping so layouts of six, eight, and ten sensors were considered. After comparing the different layouts, it was determined that employing six sensors was the best layout because adding anymore was not cost effective. Figure 10 shows the layout of the six sensors encompassing the base of the robot. The light shaded areas represent the zones in which only one sensor has a line of sight, while the dark shaded areas represent the areas where the vision of two sensors overlaps. With this layout, it is possible to narrow down the area where the sensor was dropped based on what sensors have been activated.

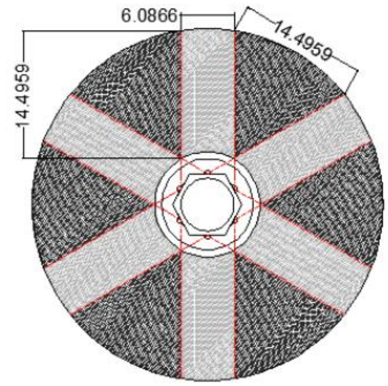


FIGURE 10: PIR Motion Sensor Layout

Another issue with the PIR motion sensor is that because it has such a wide range in both the vertical and horizontal planes, it is possible for the sensor to detect the robot's motion, even during normal operation. In order to solve this issue, a cap similar to a lampshade is placed over the top of the sensors at the base of the robot. The cap limits their view to areas well below the operation table and PFIB table where the robot will be working. The sensors are also dropped about 8 inches below the base of the robot to decrease the likelihood of them detecting the moving robot.

PIR Motion Sensor Testing. Two PIR Motion Sensors were purchased from RadioShack to test whether the sensors would be effective in detecting the motion of a dropped sample. To test the sensors, an Arduino UNO microcontroller was used. A program was made so that when one of the sensors detected motion, it would light up its corresponding LED. If both of the sensors were activated, then they would both light up their LED's. If neither motion detector was activated, then a single yellow LED would blink every second to indicate normal operation. The sensors were placed on the outside of a cardboard ring, approximately 60 degrees from each other. A "cap" was placed over the sensors so that they could only detect motion horizontally outward or downward. The range and reliability of the sensors was tested by dropping various objects with different shapes and sizes from about three feet above the sensors. The effectiveness of the sensors depended on how large the objects were and how fast they were moving. The sensors were able to detect the motion of objects about the size of wadded up paper quite well with an 80% detection rate, even when moving fast. However, the sensors were less effective when small or slender objects were dropped in front of it. To better increase their effectiveness, the sensors were placed on a table so that the object hitting and bouncing on the table was within their field of vision. This yielded better results when detecting small objects because the sensors had more time to process that an object had passed into their field of view.

Integrating the Sensors into the Universal Robot. After determining the sensor layout and testing the effectiveness of the sensors, the next step was to integrate the sensors into the Universal Robot electrical interface so that the robot can read the sensors. The Universal Robot electrical has 16 digital inputs from which the six sensors can be connected to. The Universal Robot also has 16, 24V power supply outlets in which to power external devices such as the sensors. A voltage regulator is required to step down the 24V power supply to 5V so that the motion sensors can be use the Universal Robot power supply. A L78S05 linear fixed voltage regulator was selected because it can handle voltages up to 35V, current up to 2 Amps, and it steps the voltage down to 5V. The input end of the voltage regulator is in parallel with a 0.33 μF capacitor and the output end of the regulator is in parallel with a 0.1μF capacitor to stabilize the input and output voltages. However, in order to save time and cost of shipping, the Arduino UNO's 5V supply is used to power the sensors instead.

The Universal Robot electrical interface reads a LOW digital signal as an input voltage between -3V and 5V while a HIGH digital signal identified with input voltages between 11V and 30V. Using a digital multimeter, it was found that the LOW signal sent by the PIR sensor is 0.2mV while the HIGH signal is only 3.28V. The output voltage of the sensors needs to be stepped up in order for the Universal Robot to read the sensors. In order to accomplish this, a LM741 dual op-amp is used in a non-inverting configuration with R_i of 680 ohms and R_f of 2000 ohms to give a gain of 3.94 and a resulting HIGH output voltage of 13V. The dual op-amp can be used with two sensors at the same time and can also be powered by the 24V supply voltage from the Universal Robot. After testing the circuit, it was found that Universal Robot does in fact read the sensors when the sensor outputs are boosted with the op-amp.

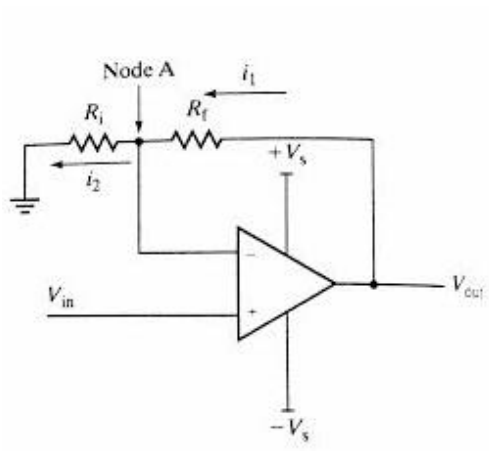


FIGURE 11: Non-Inverting Op-Amp Configuration
(*Introduction to Mechatronic Design*, Prentice Hall)

Sensing Orientation of Carriers and the Sample. Another quantity that needs to be sensed by the robot is the orientation of both the sample and the container in which the sample travels in through the pneumatic transfer system. The transfer container has a lid that swivels in order to open so that the sample can be taken out of the container. The optimum orientation for the container to be opened is to have the handle of the lid facing out towards the robot so that it can easily open the container. This makes it very important control the orientation of the container. The orientation of the sample is very important as well. The sample must be placed into the PFIB in a very specific way so that the experiment can be done properly and the sample remains secure in the PFIB. A couple methods were explored to sense orientation.

Color Sensors. One idea was to create a colored grid around the container. Each color would correspond to an angle with reference to where the lid handle on the container was. For example, say the sensor sensed the color red, which is oriented 45 degrees from the handle. Through the robots programming, it would know to rotate the container 45 degrees to have the latch facing out towards it so it could then open it and remove the sample.

An infrared emitter and detector pair was tested to sense different colors. The IR detector senses the way the IR waves reflect differently off of different colors by changing its resistance. The first circuit tested was capable of discerning light and dark colors from each other, but could not tell similar colors, such as yellow and orange, from each other. An op-amp was used to try and create a greater output voltage gap between similar colors. However, even after adding gain to the signal, the change in voltage between similar colors was not reliable enough to move forward with. Another option would need to be considered.

Machine Vision. A more sophisticated option to determine orientation that was considered is machine vision. A machine vision consists of a specialized camera that can be programmed and bright light source to illuminate the objects being viewed by the camera. The machine vision can be programmed to recognize patterns, symbols, shapes, and words, measure dimensions, and determine the orientation of the specific pattern or shape of interest. Though quite a bit more expensive than a color sensor, the machine vision was seen as the best option because of its reliability as well as not only being useful to determine orientation, but also in locating a dropped sample.

PROGRAMMING

Programming the Universal Robot. An essential part of the design of this system is to make a complex job for an operator much simpler by using a robot that can carry out the task. This is where programming is such a big component of the design. The robot must be able to be programmed so that it not only delivers the sample to and from the experimental equipment, but can also adapt to a changing environment and in a worst case scenario, be manually controlled by the operator. Part of the reason the Universal Robot was chosen is because it is one of the easiest programmable robots on the market.

All of the programming for the robot is done through the teach pendant, which is essentially a tablet from which the robot is controlled. On the teach pendant, all preferences, settings, and programs can be specified. The robot can be programmed to move in three different ways on the teach pendant. The robot can be moved into a specific position, called a "waypoint", by using buttons on the teach pendant that control each joint. This method is effective if you are not in the room with the robot and need to maneuver it to its waypoint. Another method to move the robot into a waypoint is by using the "teach" button. This method is by far the easiest because all that needs to be done is to hold down the teach button while the programmer physically grabs the robot and moves it into position. Finally, the robot can be programmed using a pose command, which is basically like traditional script code. Using script code is by far the most difficult, but if the programmer knows what they are doing, then it can be an effective method for more complex tasks. The robot can be programmed with a combination of one, two, or all of the programming methods in a single program.

The program flows by moving the robot from waypoint to waypoint. If the robot moves to a waypoint where it needs to pick up or drop off an object, then the speed and force in which the gripper opens and closes can be specified for that point in the program. If-else statements, based on the inputs from the sensors, machine vision, and also the user, control the decision making of the program.

Programming the Machine Vision. The machine vision also needs to be programmed in order for it to determine the orientation and location of the containers and samples. The chosen Cognex 1100 camera can be programmed using the Cognex Insight Explorer software with two different methods: Easybuilder and Spreadsheet. Easybuilder is, as its name implies, much easier and user friendly for those inexperienced with using spreadsheets or unfamiliar with programming. Easybuilder gives access to many tools to fulfill the needs of the user such as pattern matching, dimensioning, and text recognition. Easybuilder is a quick way to set up the program, which means that many of the advanced settings, such as accuracy and tolerance requirements, are set as default settings. This allows for the program to be set up quickly, but prevents the programmer from having complete control over the program.

This is where Spreadsheet has an advantage. Although Spreadsheet is far more complicated, it allows for full control over the machine vision program. Complex logic statements, output calculations or conversions, and data formatting can all be done on Spreadsheet. Fortunately, whenever Easybuilder is used, it creates a spreadsheet for the user allowing for a combination of the two methods to be used in a single program. This allows for the machine vision program to be set up quickly and easily, but also allows for greater control when needed.

As far as the tools used in the program, there are a lot to choose from on the In-Sight Explorer software. The tool used for this system is the PatMax Pattern tool. This is one of Cognex's most sophisticated pattern matching technologies for its ability to track almost any pattern on an object in many different positions and orientations. When using PatMax Pattern, the programmer must specify the size of the search box. The search box is the area within the image that the machine vision actively searches for the pattern. A large search box allows the machine vision to search for the pattern over a larger area, but sacrifices some operation speed in the process. The programmer must also specify what pattern they wish to track. In the case of this system, the machine vision is programmed to track the top of the large container, small container, and the mock sample. Black tape is placed on top of the containers and sample to create a distinct pattern for the machine vision to track.

The Patmax Pattern tool spits out several results that are useful for the Universal Robot. PatMax first gives a passing or failing grade for the pattern within the image that the machine vision has captured. If there is a match between the pattern that the machine vision is searching for and the pattern in the search box, the PatMax tool gives x-y coordinates of the location of the part as well as the angle that the part is oriented. These coordinates can then be sent to the Universal Robot over an Ethernet cable. This is the method used correctly orient and locate the containers and sample.

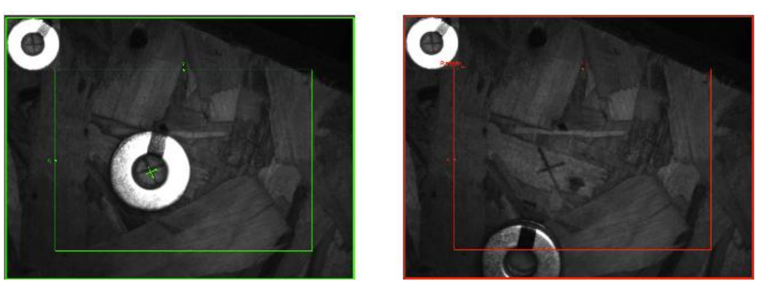


FIGURE 12: Machine Vision PatMax Pattern Tool

INSTRUMENT CELL MOCKUP

Four instrument cells in the new SPL facility have been designated for the proposed sample transfer system (see Figure 13). These cells are to be located in the center of a restricted radiation area on the facility's first floor. Early in the design process, the team decided that a complete mock-up of one of these instrument cells would be advantageous for system development. First, the team used cardboard to construct a general layout of the cell dimensions and relative location of the required instrumentation and fixtures. The INL was impressed with the results of this action and requested that a more permanent and complex mock-up be developed. Therefore, the team used wood to frame a complete 10' x 14' instrument cell. Wood was also used to construct a true to size PFIB and sample transfer table. By April 17, 2016, the team had completed mock-up of an actual instrument cell, including all necessary components for a comprehensive demonstration of the final system. The progression of the mock-up from early to final construction is shown below in Figure 14.

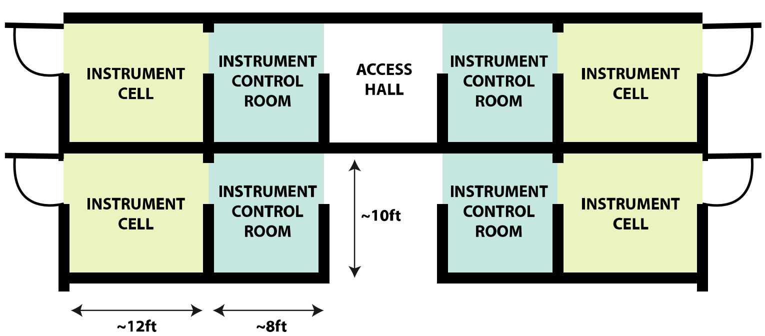
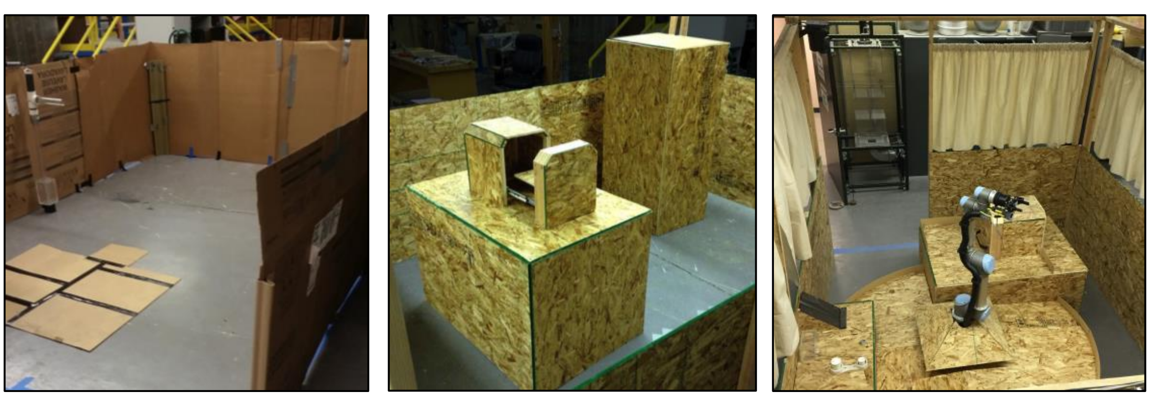


FIGURE 13: Instrumentation Cells Designated for Remote System



(a) **(b)** **(c)**

FIGURE 14: Progression of Mock-Up
(a) December 2015, (b) January 2016, (c) April 2016

FINAL BUDGET

Idaho National Laboratory gave the team an initial budget of $50,000 for the completion of this project. This money was to be allocated to the various parts of the project that will be needed, including the purchase of robotic arm, gripper, containment, sensors, vision system components and other mock up materials. As the project progressed, the scope of work increased and an additional $5,000 was given to the team to integrate and purchase Machine Vision equipment. The final budget for the project came to be $55,000 (see Table 3). A complete breakdown of the budget can be seen in Appendix Z. $52,412.34 of the $55,000.00 was used for the testing and demonstration of design.

TABLE 3: Summary of Budget

Item	Total Cost
Robot / Gripper	$ 31,523.00
Mock- Up Material	$ 1,004.60
Robot Stand	$ 116.82
Vision Systems	$ 9,471.57
Mentor Travel	$ 1,200.00
Total Spent	**$ 52,412.34**
Total Material Budget	**$ 55,000.00**
Remaining Budget	**$ 2,587.66**

Some items that were used in the testing and completion of the instrumentation cell were loaned to the team by the mentor. These items include the Stereovision system as well as the RVision pan tilt room cameras. Appendix Z also shows a complete list with costs of items that will be used in the implementation of the real instrument cell based on the team's recommendations and design. The complete cost to implement the team's recommendations, for one cell, would be roughly $100,000.00 (see Table 4). This includes a new Stereovision system by Dimension Technologies, UR-5 with gripper, Machine Vision and the RVision SEE HP room cameras. This design would be implemented in all 4 instrumentation cells for a total cost for the SPL facility of approximately $440,000.00 including a 10% contingency.

TABLE 4: Costs of Actual Equipment

Item	Total Cost
Robot / Gripper	$ 31,523.00
Machine Vision	$ 8,244.29
Stereo Vision	$ 50,000.00
Rvision	$ 10,000.00
Total	$ 99,767.29

CONCLUSION

INL has presented the SPLT design team with the need for the capability to load and unload metallurgical mounts containing beta-gamma emitting material from a transport system to examination equipment remotely in their new SPL facility. The project goals were to create a system that would perform the task of removing the metallurgical mounts from canisters, then placing them in highly sensitive and expensive instrumentation.

A UR-5 robotic arm equipped with Rvision SEE HP camera system, Cognex In-Sight Micro 1100 machine vision camera, Elmo 3-D stereovision, and PIR motion sensors was chosen and developed to meet the project specifications. This system is capable of removing samples from canisters and placing them in highly sensitive instruments through the use of programming and sensory. The UR-5 robotic arm also possesses the degrees of freedom and reach necessary for the transporting, loading, and manipulating the 1-inch met mounts. Custom holders have been designed to be integrated with the system to hold all incoming pneumatic carriers during the loading and unloading process. The degrees of freedom of the gripper also ensures that the robot can open and close the carriers, as well as place the smaller carrier inside the larger carrier for pneumatic transport. Articulation tools were also developed for situations in which a sample is dropped outside the robot’s reach.

The requirement of the system being autonomous is met through the use of sensors, machine vision, and programming. The sensors and machine vision allow the robot to adapt to different situations without any input from the operator. The programming allows the procedure run smoothly and also incorporates the inputs from the sensors and the machine vision so that the robot takes appropriate action. The autonomous component of the design is what sets this system apart from the master-slave system currently used.

Based on testing done by the group it was determined that a robotic arm has great precision and repeatability even doing multiple tasks at once. The robotic arm system can be programmed with safety measures built in which makes it safe for human interactions. The robotic arm has life expectancy of 35,000 hours. An analysis was also performed for possible radiation effects on all materials used in this project. No significant interference or degradation is anticipated, and commercially available products are recommended as adequate.

Summary of major project requirements met by the SPLT team:

- The UR-5 has an accuracy of 0.004 inches.
- The UR-5 has a repeatability of 100%.
- Material degradation from Co-60 beta and gamma radiation was found to be negligible for a minimum of 20 years, even under constant exposure.
- The vision system allows the operator to perform all tasks and processes from outside of the instrument cell.
- Only $52,400 of the $55,000 final budget was used.
- The system will be complete and deliverable by May 5, 2016.

The SPLT team is confident that the UR-5 robotic arm system they have developed and recommended in this report will provide a superior solution to INL’s project need.

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MANAGEMENT

Cody Race is a senior student of mechanical and nuclear engineering at Idaho State University. His knowledge of photography and his background education in radiation detection and nuclear radioactivity was used in the creation of the vision system. His first priority of work involved the creation of the visions system, which includes but is not limited to, the placement of the cameras, the ability for cameras to tilt and rotate, the operator control panel, the radioactive effects on the optic systems and the realistic vision for the operators while not looking directly into the room. He also has roughly 3 years of outside engineering experience with various companies so he was tasked with being the project lead as well. This included but was not limited to, scheduling of meetings, ensuring the team is meeting deadlines, project planning and communication within the team and outside vendors/mentors.

Larinda Nichols is a senior student of mechanical and nuclear engineering at Idaho State University. She also had the privilege of working with the Idaho National Laboratory as an intern during the summer of 2015. Her industrial and educational background in nuclear radioactivity, radiation detection, and materials science was utilized in selecting materials for in this project. Larinda was also responsible for ensuring that all hardware used in the final design met radiological standards as given by the INL.

Jerron Berrett is a senior student of mechanical engineering at Idaho State University. Jerron was responsible for the kinematics of the robot. His background education includes classes in kinematics and materials that aided him for this scope of work. He was to ensure that the robot would have the necessary degrees of freedom to be able to do the required tasks as defined by the process, which includes but is not limited to, picking up the sample, placing the sample in the instrument, and being able to pick up a sample if dropped.

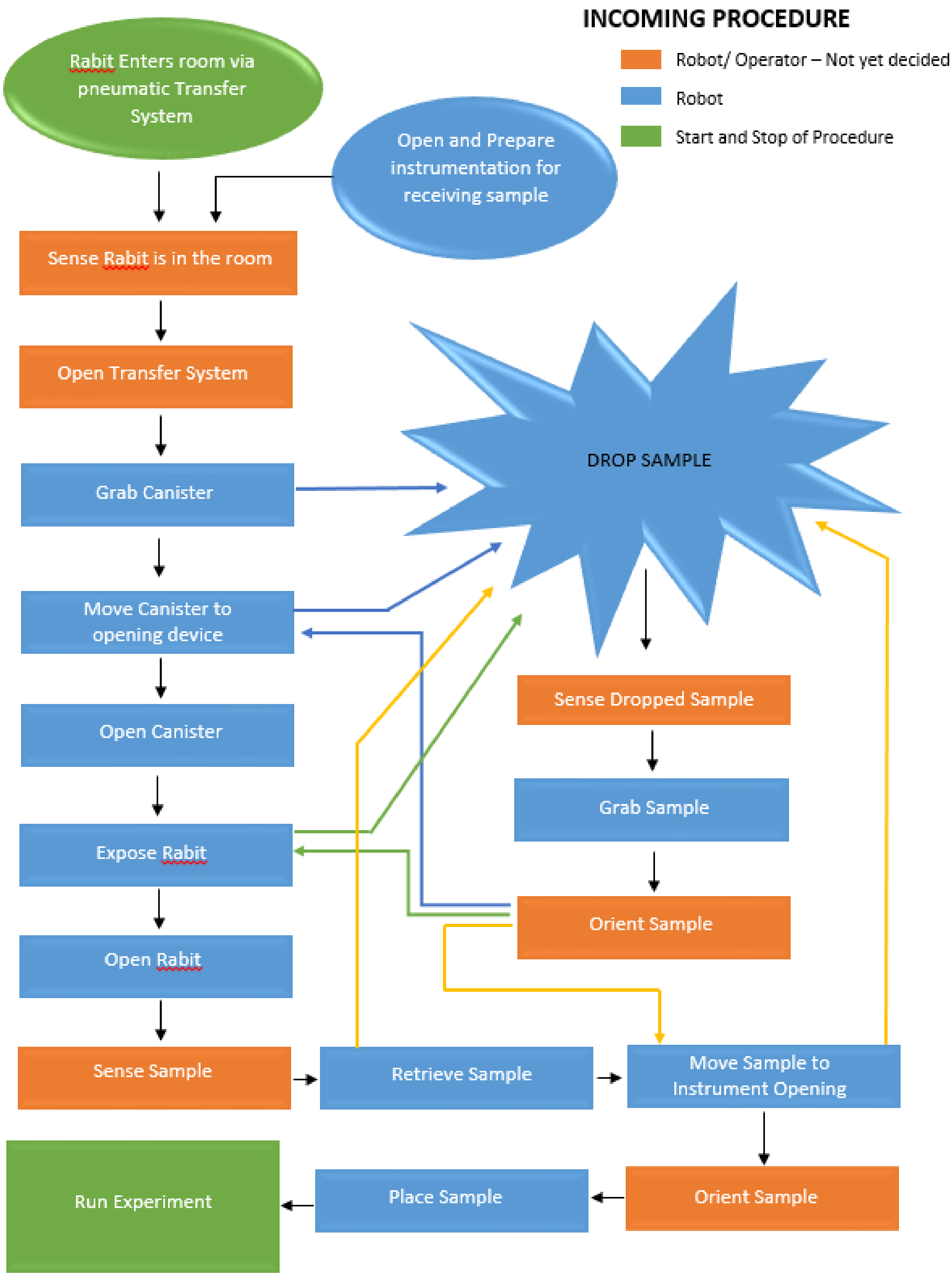
Sage Thibodeau took a semester long mechatronics class that explored the disciplines required for the design of automated robotic systems. These disciplines include mechanical, electronic, control, and computer programming design. Sage was in charge of electronics and controls, which included but was not limited to, selecting and integrating sensors, choosing a microcontroller or “brain” of the system, coding of the system, making sure the power source is compatible with the system, and designing any other electrical circuit components necessary.

APPENDIX A: Decision Matrix

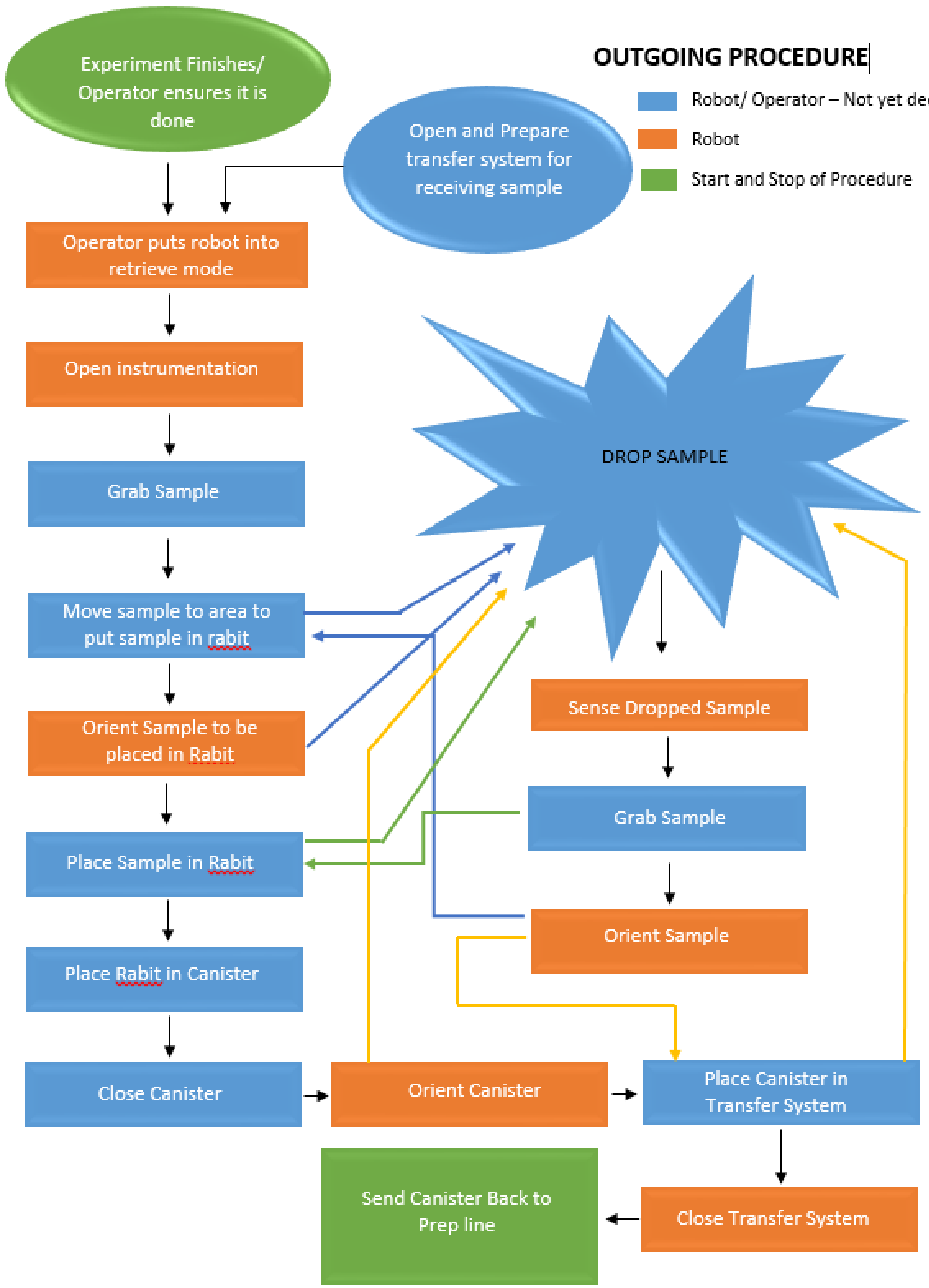
Master Slave Manipulator	1
Armour Suit	2
Robotic Arm	3
UGV	4
Chute/Conveyor Belt	5
Crane/ Claw	6
Heli-Quad Copter	7

		Concept						
Spec	**Weight**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Removal/return of sample from pneumatic transfer system.	**5**	**5**	**5**	**5**	**5**	**0**	**5**	**3**
Removal/return to rabbit	**5**	**4**	**5**	**5**	**5**	**0**	**3**	**3**
Removal/return to instruments	**5**	**4**	**5**	**5**	**5**	**0**	**1**	**1**
Vision (Optics/window)	**3**	**2**	**5**	**3**	**3**	**3**	**3**	**3**
Ability to react to dropped sample	**5**	**5**	**5**	**3**	**5**	**0**	**5**	**5**
Accuracy	**5**	**5**	**5**	**5**	**1**	**3**	**5**	**3**
Repeatability	**5**	**3**	**5**	**5**	**1**	**0**	**1**	**0**
Multi-personnel operation (lefty/Righty)	**4**	**2**	**5**	**5**	**5**	**5**	**5**	**5**
A total dose of 1 x 10^6 Rad shall be the basis for equipment radiological design (2 Ci Co 60)	**5**	**5**	**0**	**5**	**5**	**5**	**5**	**5**
No sharp edges	**3**	**5**	**5**	**5**	**5**	**5**	**4**	**5**
Safety	**3**	**3**	**1**	**5**	**5**	**4**	**2**	**2**
10 year life cycle	**3**	**5**	**0**	**5**	**5**	**5**	**5**	**1**
Easy to Upgrade/ Modular	**3**	**0**	**2**	**5**	**5**	**0**	**0**	**5**
Cell Size (10.5' X 8')	**4**	**3**	**5**	**4**	**5**	**3**	**5**	**5**
Lifetime Cost	**2**	**1**	**4**	**2**	**2**	**5**	**3**	**5**
Complexity	**2**	**5**	**0**	**2**	**2**	**5**	**4**	**0**
	Total	**217**	**212**	**253**	**247**	**143**	**216**	**198**

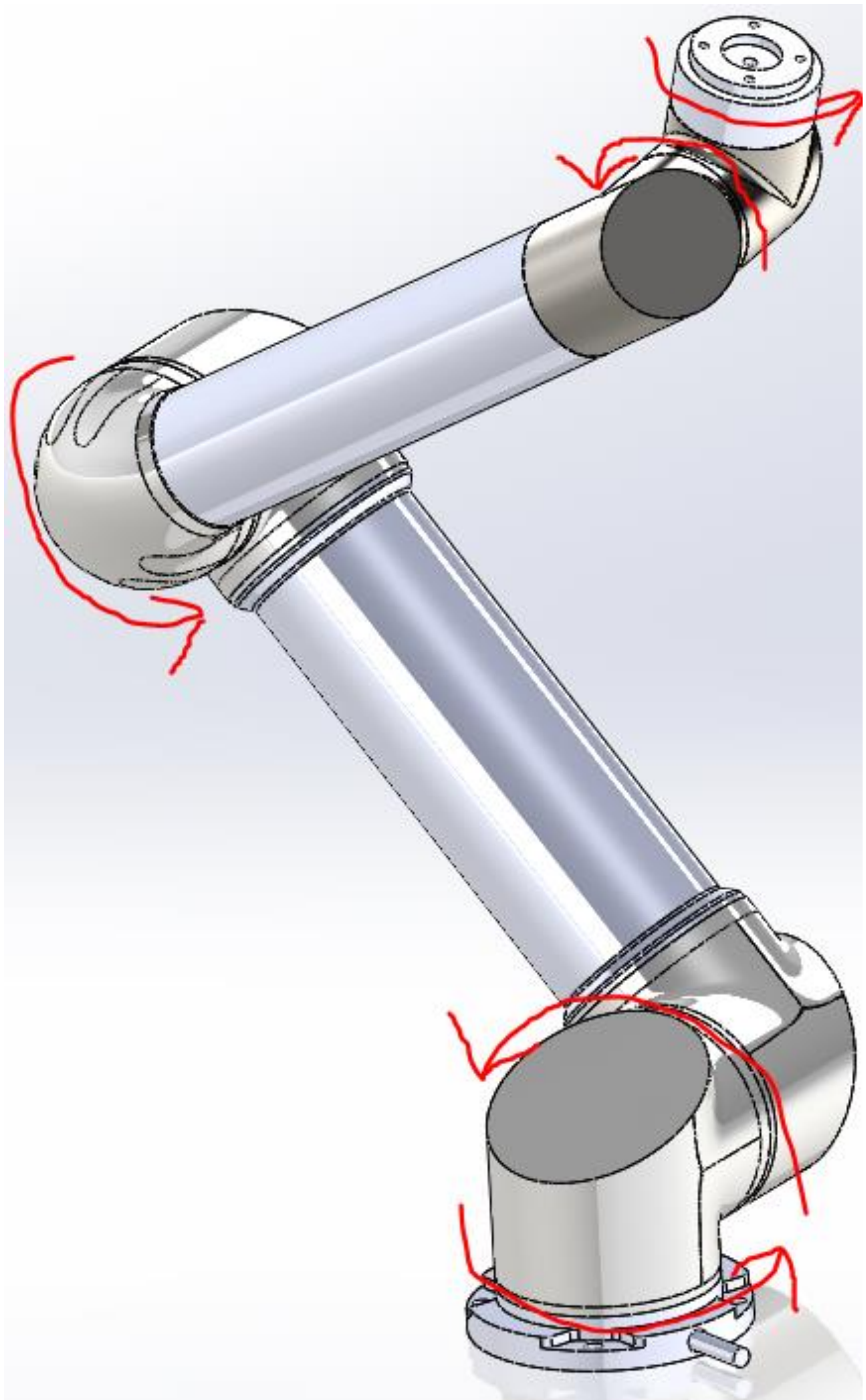
APPENDIX B: Incoming Procedure Flowchart



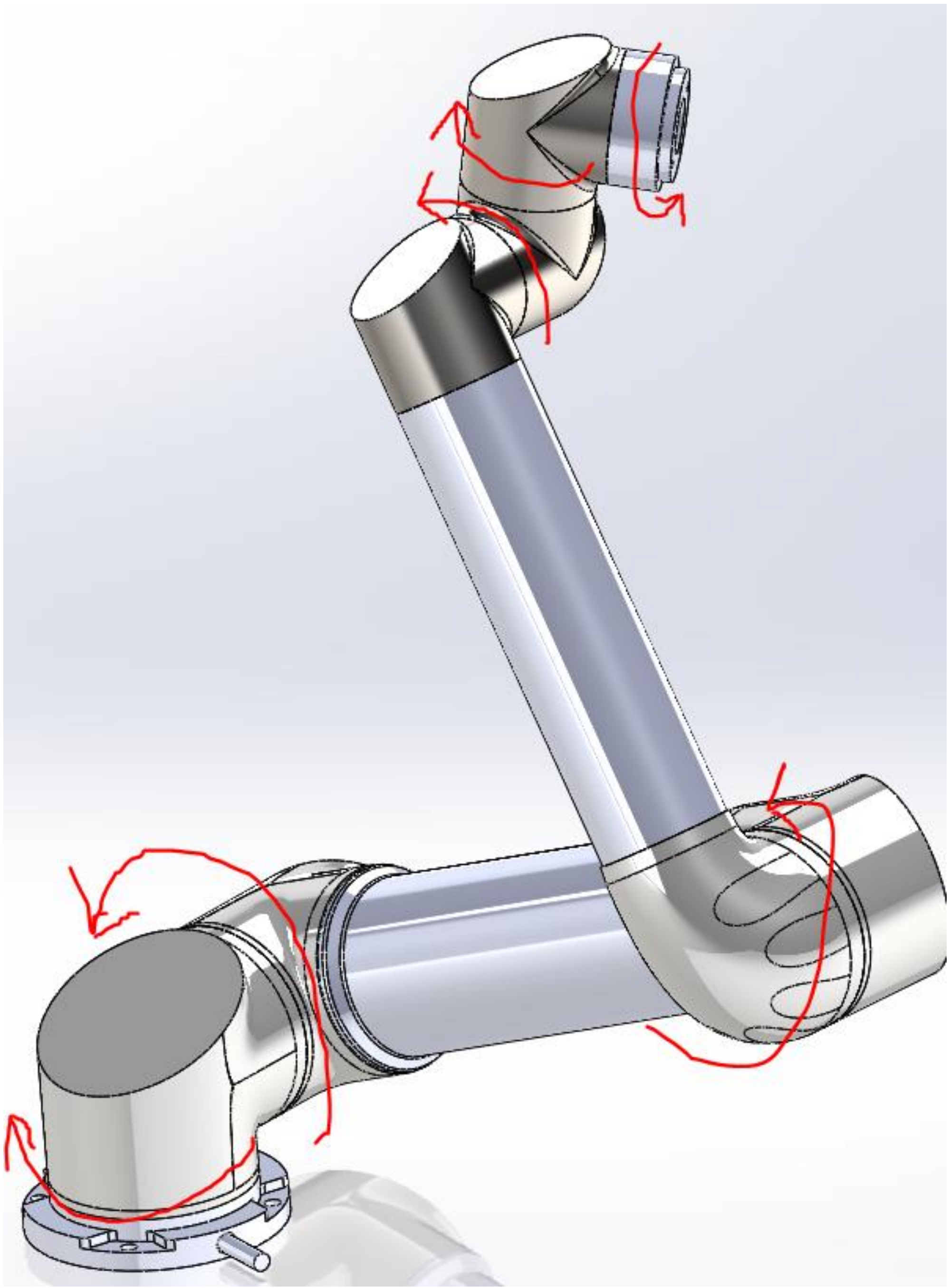
APPENDIX C: Outgoing Procedure Flowchart



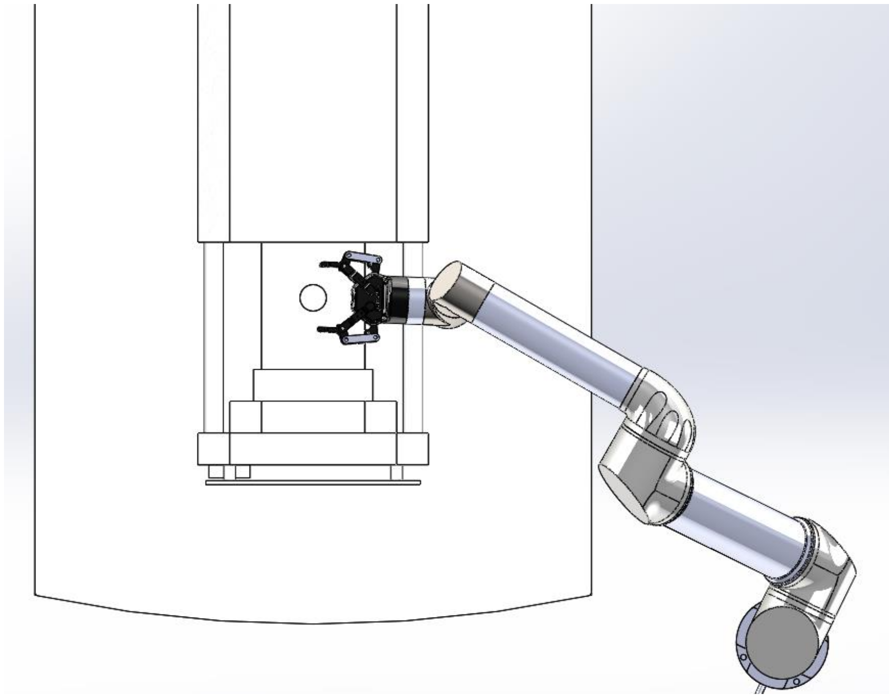
APPENDIX D: Five Degrees of Freedom

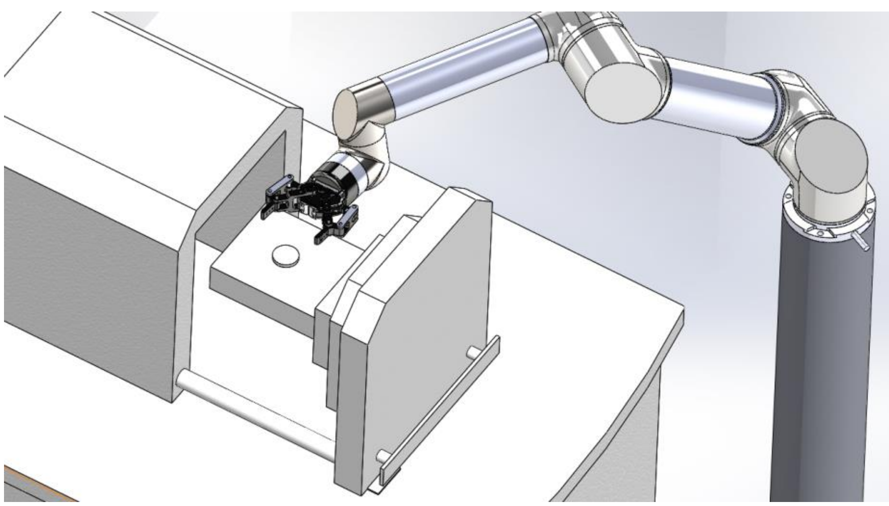


APPENDIX E: Six Degrees of Freedom

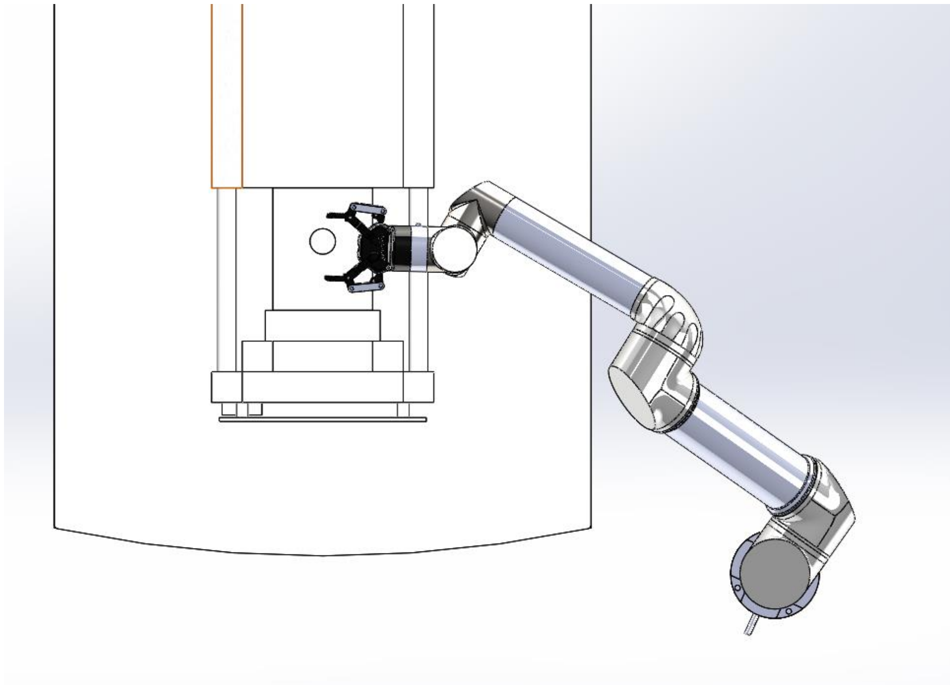


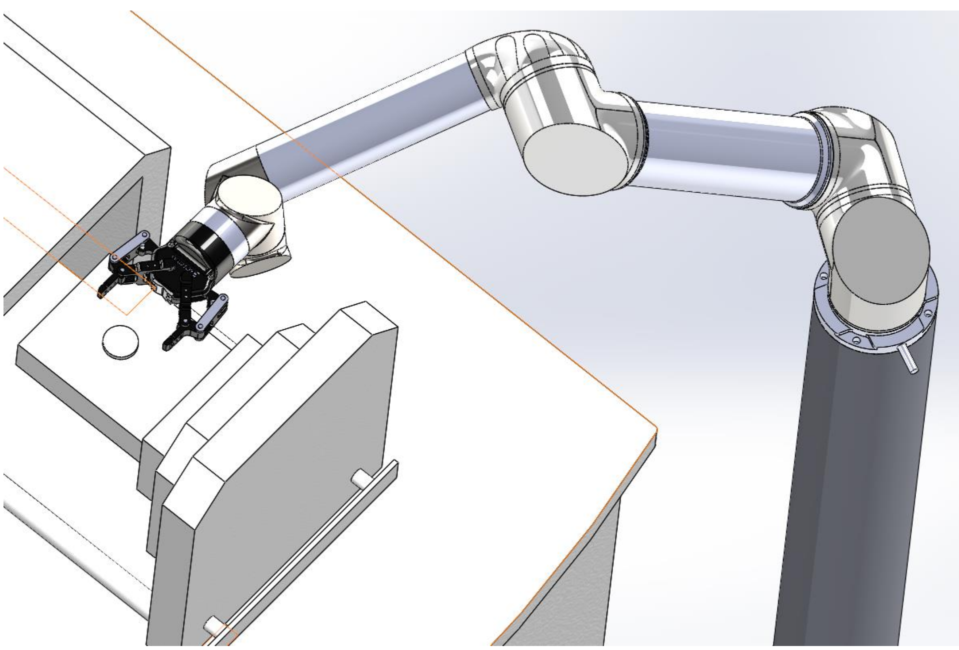
APPENDIX F: Five Degrees of Freedom – Robotic Arm Placement



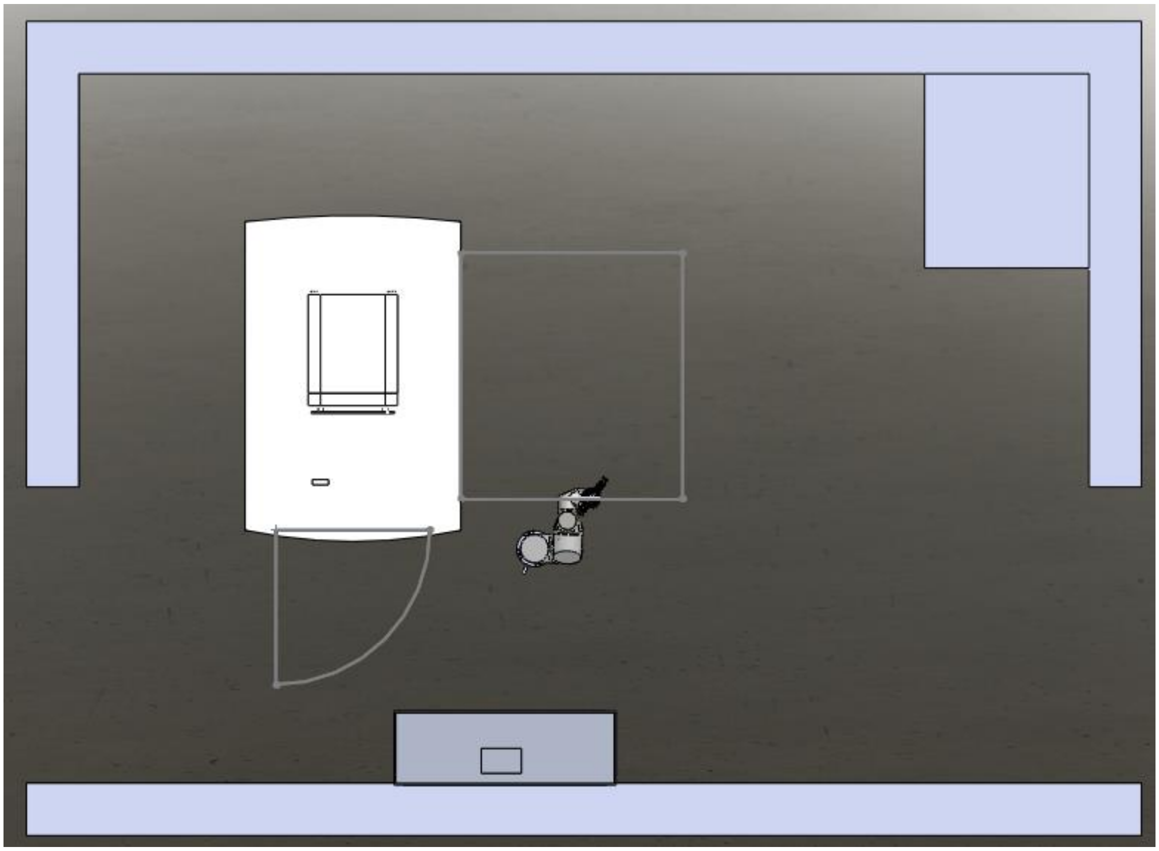


APPENDIX G: Six Degrees of Freedom – Robotic Arm Placement

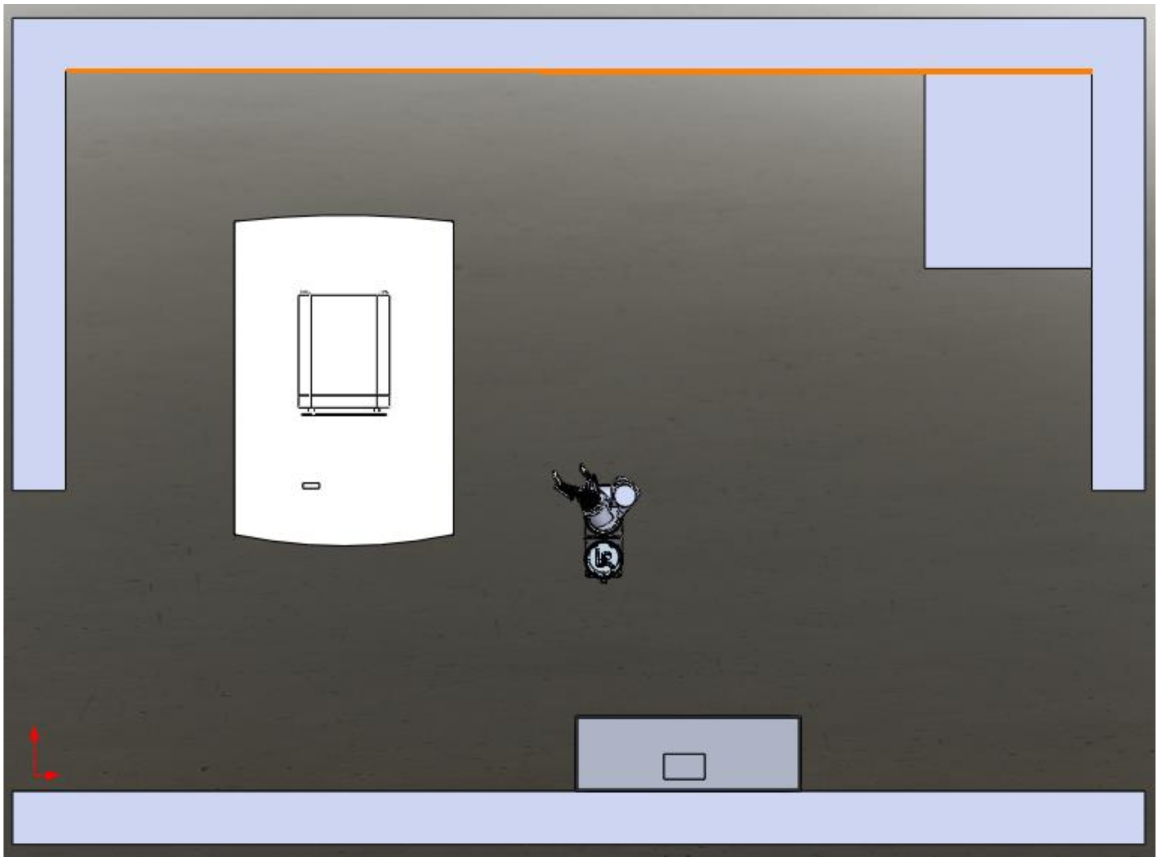




APPENDIX H: Sample Room Layout – UR5

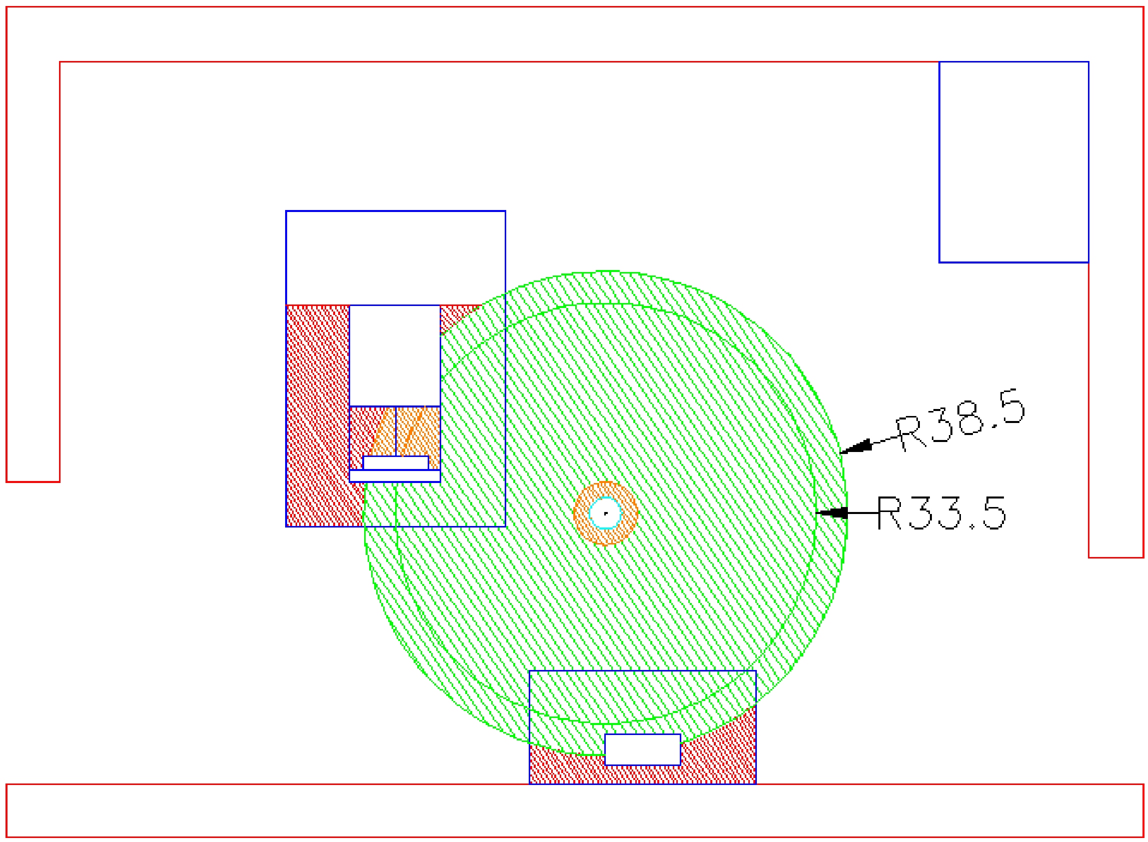


APPENDIX I: Sample Room Layout – UR10

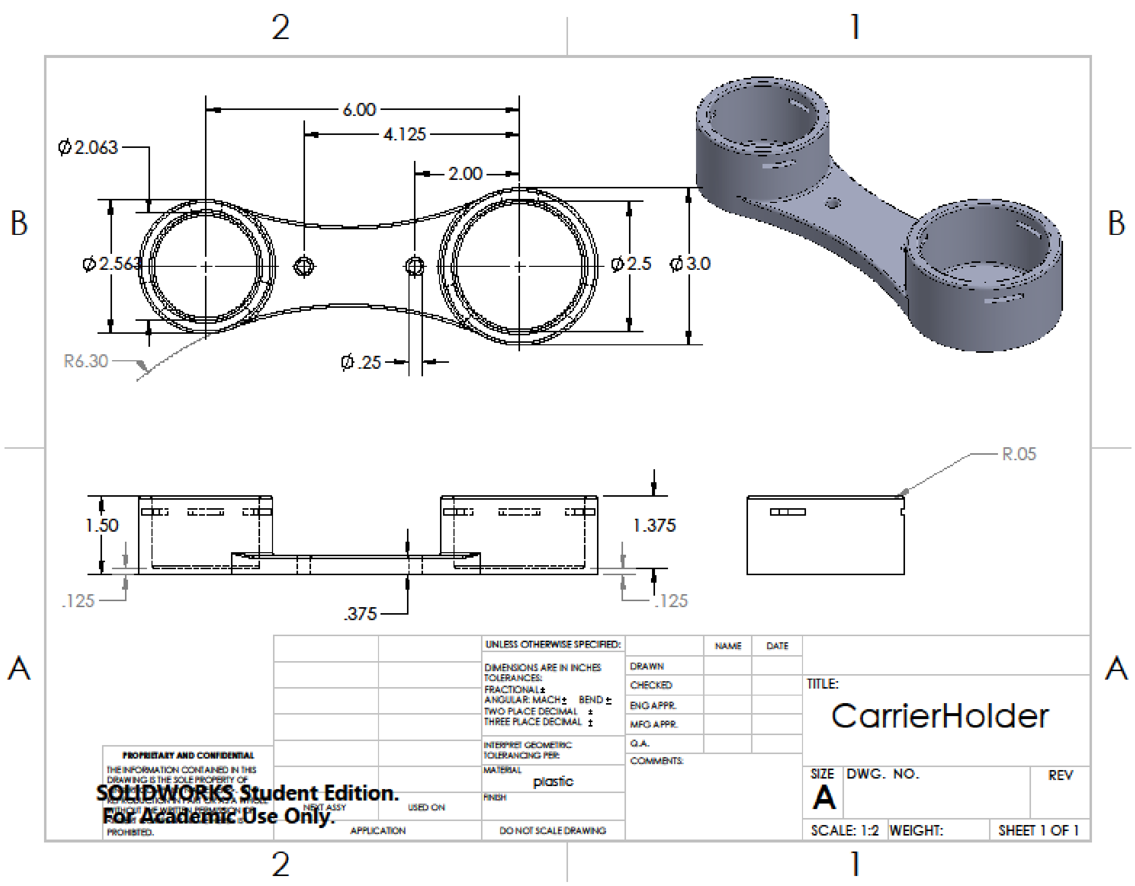


APPENDIX J: Instrument Cell Mockup

APPENDIX K: AutoCad Rendering of Instrument Cell – Robot Reach



APPENDIX L: Carrier Holder



APPENDIX M: Carrier Holder Hand Calculations

Carrier holder — Jerron Berrett

larger diameter circle (See Appendix for drawing of Part)

Outside diameter = 3"

inside diameter = 2.5'

hight = 1.5"

$S_y = 6100$ Psi

Assumed Force of 100 LBF (This Force is acting on one of the sides)

$$\sigma = \frac{32Fl}{\pi(d_o^3 - d_i^3)} \quad \text{where } l = \text{hight}$$

$$\sigma = \frac{32(100\,LBF)(1.5\,in)}{\pi(3\,in^3 - 2.5\,in^3)} = 64.67 \text{ Psi}$$

No Torque So $\sigma' = \sigma$

$$n = \frac{S_y}{\sigma'} = \frac{6100\text{ Psi}}{64.67\text{ Psi}} = 94$$

Factor of safety of $n = 94$

Smaller diameter circle

outside diameter = 2.563"

inside diameter = 2.063"

hight = 1.5"

$S_y = 6100$ psi (same material)

Using same Assumed Force of 100 LBF

$$\sigma = \frac{32Fl}{\pi(d_o^3 - d_i^3)}$$

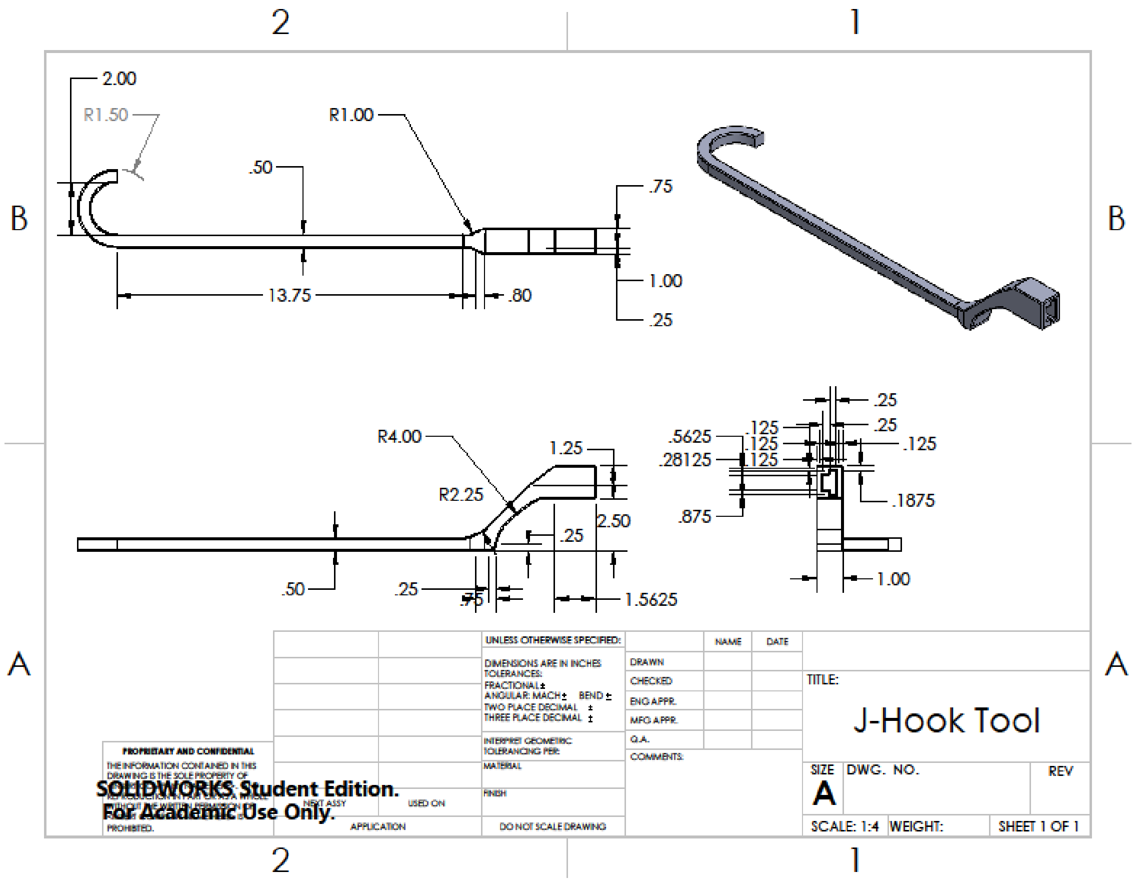
$$\sigma = \frac{32(100)(1.5\,in)}{\pi(2.563\,in^3 - 2.063\,in^3)} = 189.7 \text{ Psi}$$

$\sigma' = \sigma$

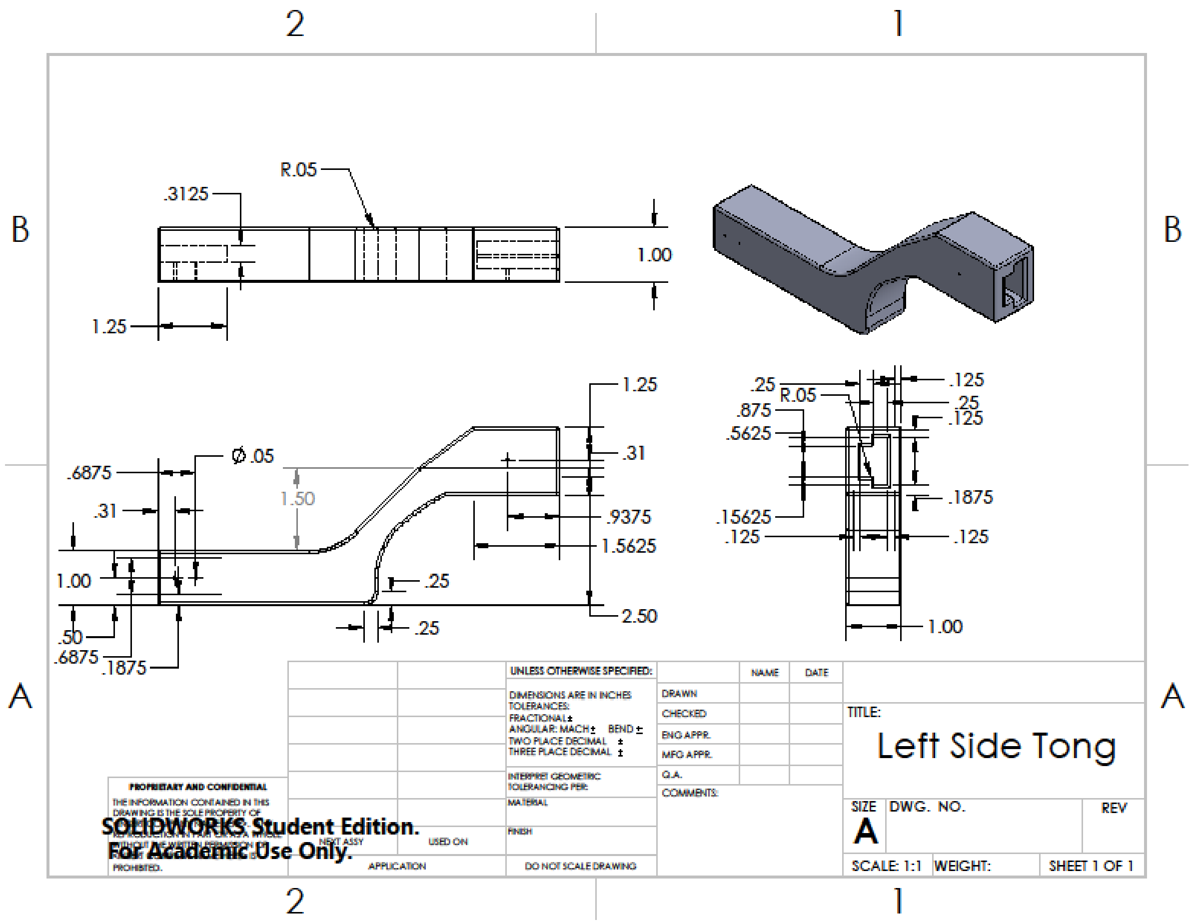
$$n = \frac{S_y}{\sigma'} = \frac{6100\text{ Psi}}{189.7\text{ Psi}} = 32$$

Factor of safety $n = 32$

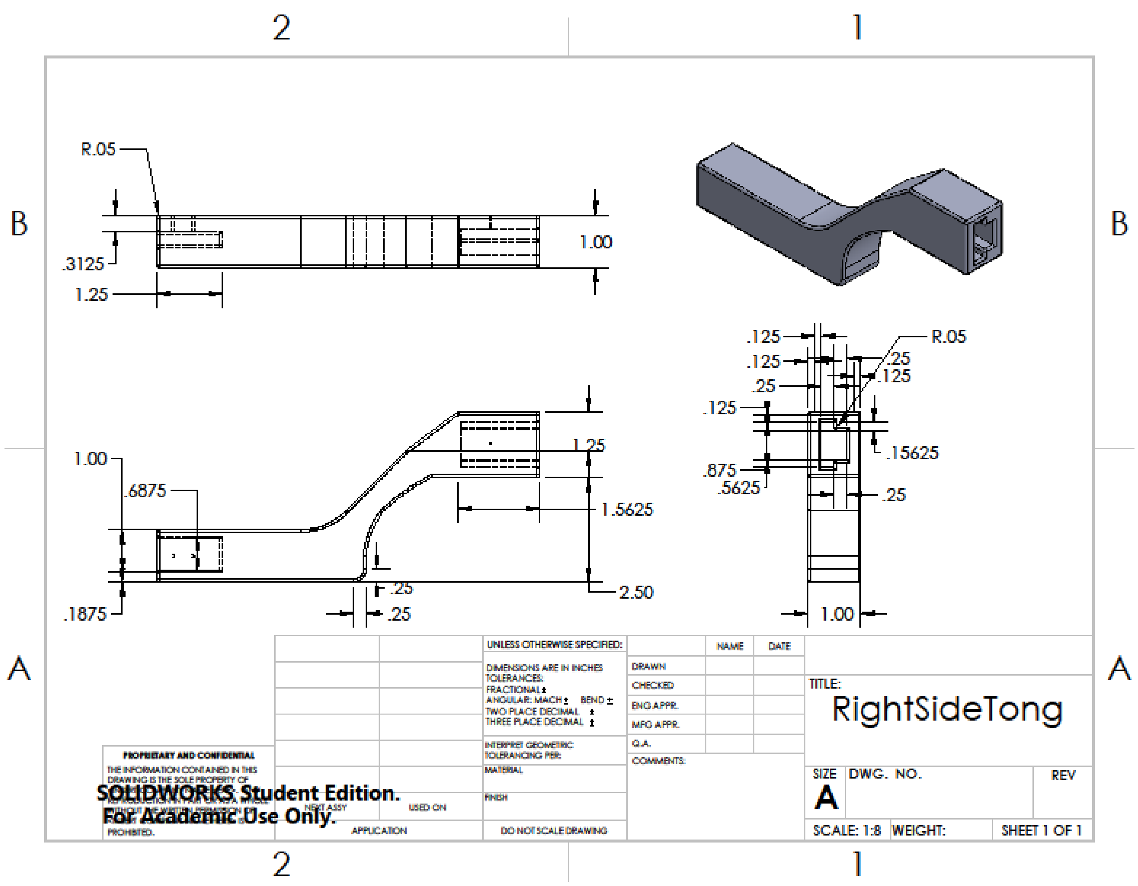
APPENDIX N: J-Hook Articulation Tool



APPENDIX O: Tongs Articulation Tool – Left Side



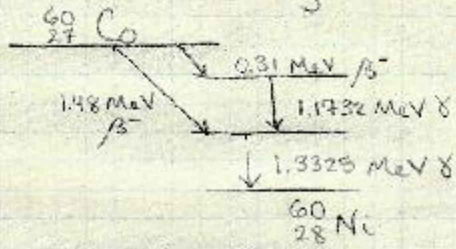
APPENDIX P: Tongs Articulation Tool – Right Side



APPENDIX Q: Radiation Calculations

RADIATION CALCS (For Appendix) LARINDA NICHOLS 1/1

Cobalt-60 Decay Scheme



Total $\beta^- \approx 1.79$ MeV

Total $\gamma \approx 2.5$ MeV

No α radiation

Absorbed Dose for Plexi-Glas deterioration:

Insignificant	0.1 - 20 MRad
Moderate	20 - 300 MRad
Considerable	300 - 10,000 MRad

[From "Radiation Damage to Materials", C228, Mod 4]

Rule of Thumb (Point Source) - γ-rays ~ 2.0 MeV

$$\frac{6 \times \text{Source Curies} \times E\ \text{MeV}}{(r^2_{ft})} = \frac{6(1\,\text{Curie})(2.5\,\text{MeV})}{r^2} = \frac{15}{r^2}$$

At ~ 1 ft (for Plexiglas)

$$\frac{15\ \text{Rad}}{\text{Hr}}\left(\frac{24\ \text{Hr}}{\text{Day}}\right)\left(\frac{365\ \text{D}}{\text{yr}}\right) \approx 22 \text{ years (constant exposure to Co-60)}$$

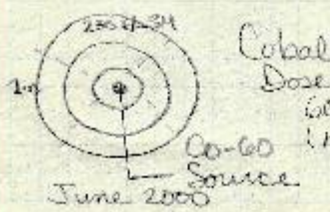
γ-range → Through Aluminum

β^- range in Aluminum $I = I_0 e^{-\mu t}$, μ^{β^-}, μ^{γ}

1 MeV - 3 MeV → (160 μm - 550 μm)

Radiation Flux: $\phi(r) = \frac{S}{4\pi r^2}$ → Rule of thumb ~2 MeV, Flat Profile

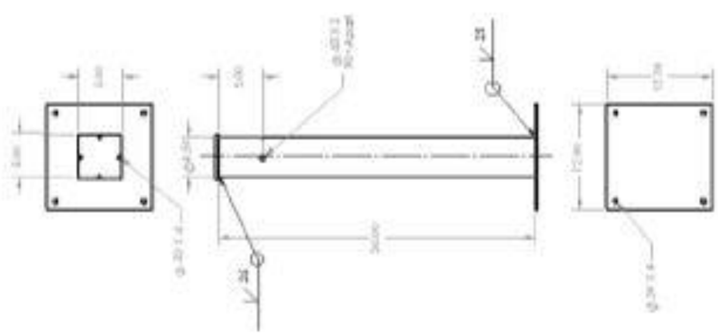
Dose: Φ (radiation Fluence) [cm^{-2}]
γ μ (linear attenuation coefficient) [cm^{-1}]
E (photon energy) [MeV]



Cobalt-60 → University of Florida
Dose Map
600 C
(krad/h)

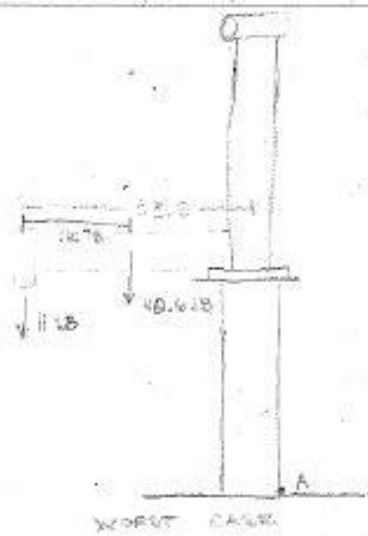
Oakridge National Laboratory
"Designing equipment for use in γ radiation environment"
Commercial Cables ~ 1 MGy

APPENDIX R: Robotic Stand



APPENDIX S: Robotic Stand Calculations

MOMENT ON STAND



$P_1 = 11$ LB

$P_2 = 40.6$ LB

$M_1 = 11\text{ LB}(55.5") = 565.5$ LB·IN

$M_2 = 40.6\text{ LB}(16.75") = 680.05$ LB-IN

$\sigma_{P_1} = P_1/A = 11\text{ LB}/6.28\text{ IN}^2 = 1.752\text{ LB/IN}^2$

$\sigma_{P_2} = P_2/A = 40.6\text{ LB}/6.28\text{ IN}^2 = 6.465\text{ LB/IN}^2$

$I = \frac{\pi d^3 t}{4} = \frac{\pi(4\text{ IN}^3)(1")}{4} = 50.27\text{ IN}^4$

$\sigma_{M_1} = M_1(d/2)/I = 568.5\text{ LB-IN}(4"/2)/50.27\text{ IN}^4$

$= 14.662\text{ LB/IN}^2$

$\sigma_{M_2} = M_2(d/2)/I = 680.05\text{ LB-IN}(4"/2)/50.27\text{ IN}^4$

$= 27.06\text{ LB/IN}^2$

$\sigma_x = 1.752 + 6.465 + 14.662 + 27.06 = 49.9 \simeq 50\text{ LB/IN}^2$

$\sigma_x = 0$ $\tau = 25\text{ LB/IN}^2$

$\sigma_y = -50\text{ LB/IN}^2$

$\sigma' = \sqrt{\left(\frac{50^2}{2}\right) + (25\text{ LB/IN})^2} = 43.3\text{ LB/IN}^2$

$n = \frac{S_y}{\sigma'} = \frac{44100}{43.3} = 1020.7$ ★ SHOULD BE ABLE TO W/STAND MOMENT & STRESSES

LOAD ON CYLINDRICAL STAND

ROBOT WEIGHT → $F = 40.6$ LBS

$$P_{cr} = A\left[S_y - \left(\frac{S_y}{2\pi}\frac{l}{k}\right)^2 \frac{1}{CE}\right]$$

$$A = \frac{\pi}{4}D_1^2 - \frac{\pi}{4}D_2^2$$

$D_1 = 4.5$; $D_2 = 3.5$

$$= \frac{\pi}{4}(4.5^2) - \frac{\pi}{4}(3.5^2) = 6.28 \text{ IN}^2$$

MATWEB AISI 1010 STEEL CD

$S_u = 52900$ psi

$S_y = 44200$ psi

$E = 29{,}000{,}000$ psi

– C FROM TABLE 4-2 SHIGLEY'S 9TH MECHANICAL ENGINEERING DESIGN BUDYNAS & NISBETT

$C = 1.2$

$l = 36'' = 3$ FT

$$k = \sqrt{I_x / A}$$

$$I_x = \pi/64\,(D^4 - d^4) = \frac{\pi}{64}(4.5^4 - 3.5^4) = 12.768 \text{ IN}^4$$

$$k = \sqrt{\frac{12.768 \text{ IN}^4}{6.28 \text{ IN}^2}} = 1.426 \text{ IN}$$

$$P_{cr} = 6.28 \text{ IN}^2\left[44200 \text{ LB/IN}^2 - \left(\frac{44200 \text{ LB/IN}^2}{2\pi}\frac{36 \text{ IN}}{1.426 \text{ IN}}\right)^2 \frac{1}{1.2(29{,}000{,}000 \text{ LB/IN}^2)}\right]$$

$$P_{cr} = 6.28 \text{ IN}^2\left[44200 \text{ LB/IN}^2 - 906.299 \text{ LB/IN}^2\right]$$

$= 271884.44$ LB → 271 KLB

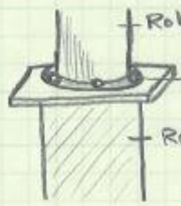
FACTOR OF SAFETY

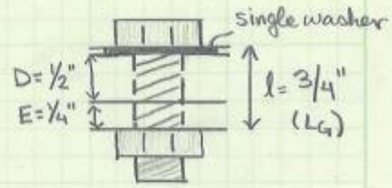
$$n = \frac{271884.44 \text{ LB}}{40.6 \text{ LB}} = 6696$$

* SHOULD BE ABLE TO HOLD LOAD

ME 4496B 2/21/2015 LARINDA NICHOLS 1/3

Robot Stand Bolt Calculations





$P_T = 40.6$ lb.

$A = \pi/4\,(6in)^2 = 28.27 in^2 - \pi/4\,(5.5in)^2 = 4.52\ in^2$

$\frac{P_T}{A} = \frac{40.6\ lb}{4.52\ in^2} \cong 9\ psi$

Each Bolt, $P \approx 10.15$ lb

Choice of Bolts: Grade SAE No. 2 Steel → $S_p = 33$ Kpsi*

* Mechanical Engineering Design – Shigley Budynas and Nisbett, Ed. 8
→ Table-8.9

Equations (from Shigley's) Ch. 8

Size Designation → 8mm Nominal M. Dia
*Table-A-31 Mfg. Suggestion URobots Inc. (Manual)
H = 6.8 mm
W = 13 mm
h = 35 mm

$L_T = 2d + 6 = (2(8\ mm) + 6) = 22\ mm$
$l_d = L - L_T = 13\ mm$
$l_t = l - l_d = 19.05mm - 13mm = 16.05\ mm$

Stiffness E (Steel) = Stainless Steel = 27.6 Mpsi / 190 GPa

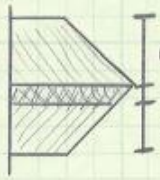
$A_d = \frac{\pi d^2}{4} = \frac{\pi (64 mm^2)}{4} = 50.27\ mm^2$ $A_t = 36.6\ mm^2$ (coarse) * Table 8-1

$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{(50.27 mm^2)(36.6 mm^2)(190\times10^9 N/m^2)\left(\frac{1\times10^{-6} m^2}{mm^2}\right)}{(50.27\ mm^2)(16.05mm) + (36.6 mm^2)(13mm)}$

$k_b \cong 272{,}547\ N/mm \cong 2.73\times10^8\ N/m$

Eq. 8-20 (p.415) $k = \frac{0.5774\pi E d}{\ln\left[\frac{(1.155t+D-d)(D+d)}{(1.155t+D+d)(D-d)}\right]}$

Upper Frustrum :



$t_1 = 9.525mm = 0.009525m$
$E_1 = 71.7 GPa = 71.7\times10^9 N/m^2$
$D_1 = d_w = 13mm = 0.013m$

$$k_1 = \frac{0.5774\pi\,(71.7\times10^9 N/m^2)(0.008m)}{\ln\left[\frac{(1.155(0.0095)m + 0.005m)(0.021m)}{(1.155)(0.0095)m + 0.021m)(0.005m)}\right]}$$

$$k_1 = 1.408\times10^9\ N/m$$

Center Frustrum :

$t_2 = 3.175mm = 0.003175m$
$E_2 = E_1 = 71.7\times10^9 N/m^2$
$\alpha = 30°$
$D_2 \Rightarrow D_1 + 2(t_1 \tan\alpha)$
$D_2 \Rightarrow (0.013m) + 2(0.009525m \tan 30°)$
$D_2 = 0.024m$

$$k_2 = \frac{0.5774\pi\,(71.7\times10^9 N/m^2)(0.008m)}{\ln\left[\frac{(1.155(0.0032)m + 0.016m)(0.032m)}{(1.155)(0.0032)m + 0.032m)(0.016m)}\right]}$$

$$k_2 = 11.309\times10^9\ N/m$$

Lower Frustrum :

$t_3 = 6.35mm = 0.00635m$
$E_3 = 190\times10^9 N/m^2$
$D_3 = D_1 = 0.013m$

$$k_3 = \frac{0.5774\pi\,(190\times10^9 N/m^2)(0.008m)}{\ln\left[\frac{(1.155(0.00635)m + 0.005)m(0.021m)}{(1.155(0.0095)m + 0.021m)(0.005m)}\right]}$$

$$k_3 = 5.713\times10^9\ N/m$$

$$\frac{1}{k_m} = \frac{1}{1.4\times10^9} + \frac{1}{11.3\times10^9} + \frac{1}{5.7\times10^9} = 9.782\times10^{-10} m/N$$

so, $k_m = 1.02\times10^9 N/m = 10.2\times10^8 N/m$

$$C = \frac{k_b}{k_b + k_m} = \frac{2.73\times10^8 N/m}{12.93\times10^8 N/m} = 0.2111$$

L. Nichols 3/3

Preload (Assuming Non-Permanent Joint)

$F_i = 0.75 F_p$ (Eq 8.30)*
$A_t = 36.6 mm^2 = 0.0567 in^2$
$S_p = 33 Kpsi$

So, $F_p = A_t S_p = 0.0567 in^2 (33{,}000 lb/in^2)$ * Eq. 8.31
$F_p = 1871.1 lb$

$F_i = 0.75 (1871.1 lb) = 1309.77 lb$

FACTOR OF SAFETY (Eq. 8-28)*

$$n = \frac{S_p A_t - F_i}{CP} = \frac{33{,}000 lb/in^2 (0.0567 in^2) - 1309.77 lb}{0.2111 (40.6 lb)}$$

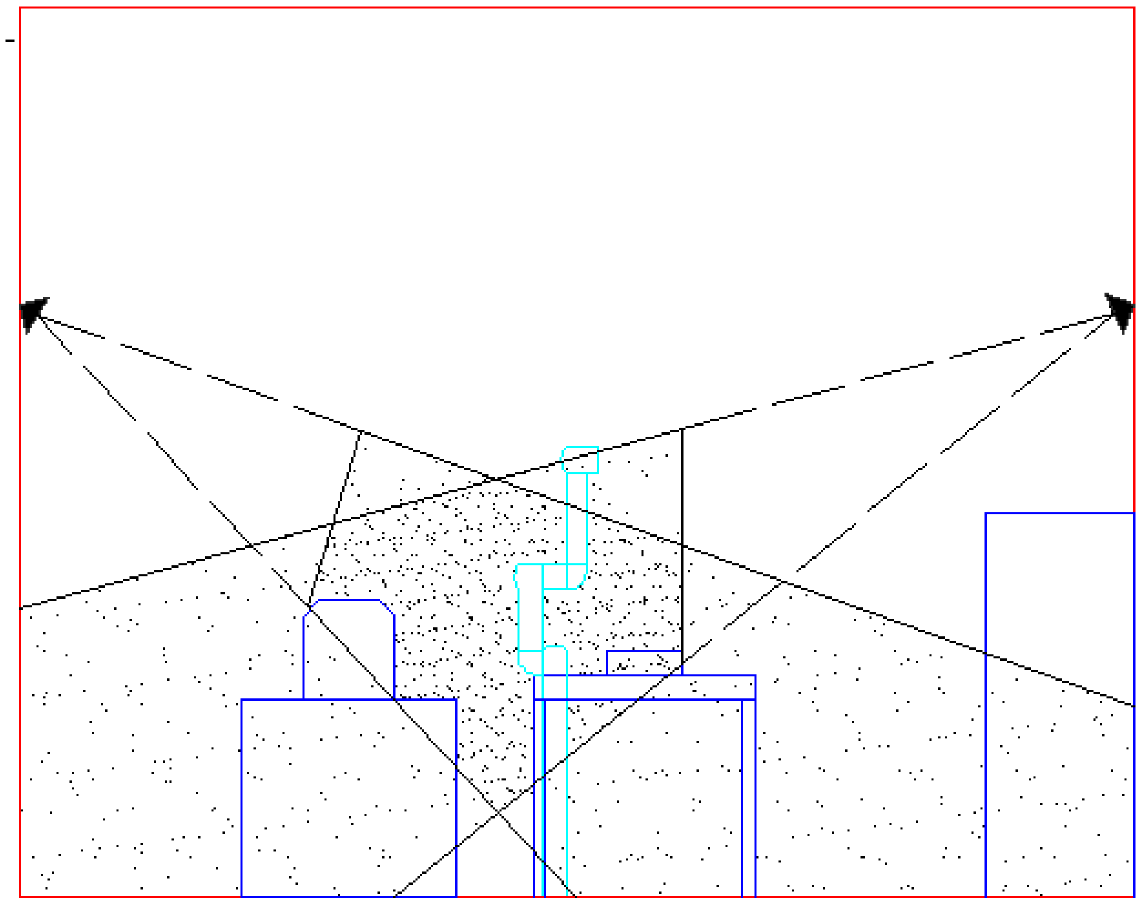
$n = 65.5$

★ Summary of Results (Fasteners for Robot Stand)

Qty	Description	Size (D)	
4	SAE No 2 Steel Bolts	8mm	(S.S.)
4	1mm Plain Washers	12mm	(S.S.)
4	Reg Hexagonal Nuts	13mm	(S.S.)

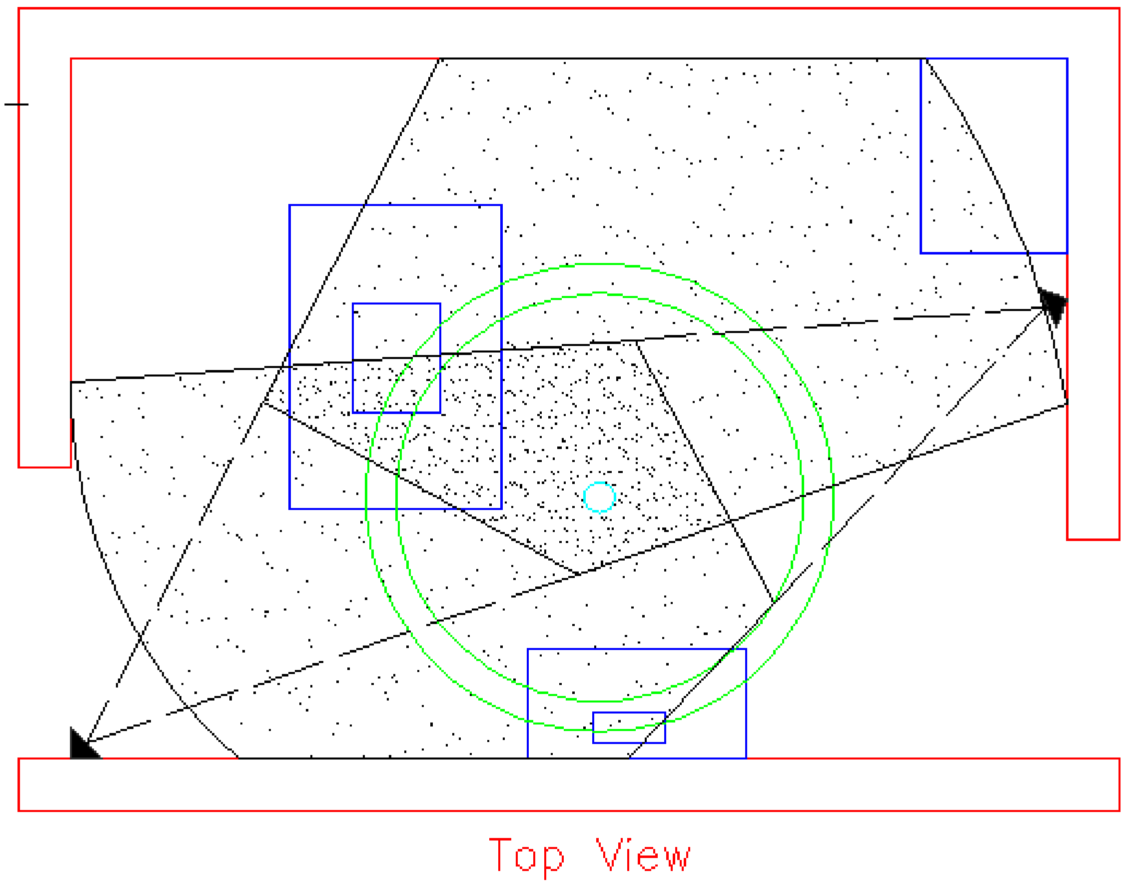
★Factor of Safety: 65.5

APPENDIX T: Robotic Camera System Placement – Side Wall View



Side Wall View

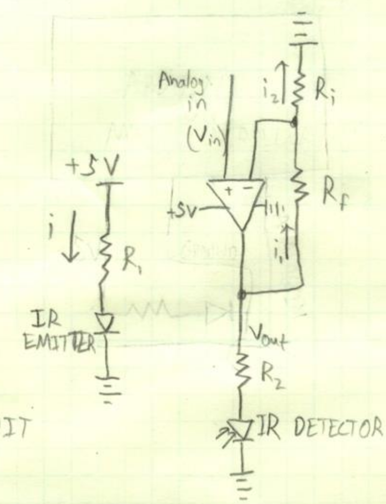
APPENDIX U: Robotic Camera System Placement – Top View



APPENDIX V: Color Sensor

1

COLOR SENSOR



- WANT TO SENSE COLOR OF OBJECTS
- SENSOR WILL USE REFLECTANCE OF IR WAVES ON DIFFERENT COLORED OBJECTS
- OP-AMP USED TO AMPLIFY SIGNAL AND BETTER DISCERN COLORS OF OBJECTS

EMITTER CIRCUIT

$i = \frac{V}{R_1}$

$V = V_s - V_f$ V_s = SUPPLIED VOLTAGE

V_f = FORWARD VOLTAGE

$V_s = 5V$ $V_f = 1.8V$ (max)

i = FORWARD CURRENT

$i = 100mA$

$100mA = \frac{5V - 1.8V}{R_1}$

$R_1 = \frac{5V - 1.8V}{0.1A} = 32\Omega$

$V_f = 1.5V$ (TYPICAL)

$R_1 = \frac{5V - 1.5V}{0.1A} = 35\Omega$

CIRCUIT TESTED WITH $R_1 = 1k\Omega$ RESISTOR

$i = \frac{5V - 1.8V}{1000\Omega}$

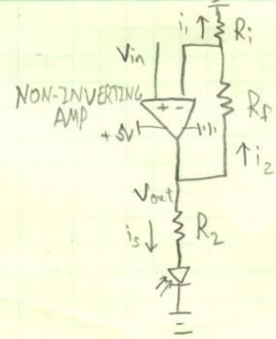
$i = 3.2mA$

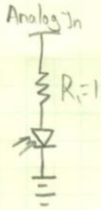
THE IR EMITTER EMITS PROPERLY WITH $1k\Omega$ RESISTOR

2

COLOR SENSOR

DETECTOR CIRCUIT





- ORIGINAL CIRCUIT USED
- DID SENSE DIFFERENT COLORS
- HOWEVER, IT DID NOT DISCERN SIMILAR COLORS WELL
- Ex: BLACK & BLUE, YELLOW & ORANGE, etc...

- OP-AMP ADDED IN HOPES OF DISCERNING SIMILAR COLORS BETTER

$i_2 = \frac{V_{out} - V_{in}}{R_f}$ $\quad i_1 = \frac{V_{in} - 0}{R_i}$ ← GROUND REFERENCE

NO CURRENT GOES INTO INVERTING INPUT SO:

$i_2 = i_1$

$$\frac{V_{out} - V_{in}}{R_f} = \frac{V_{in} - 0}{R_i}$$

$$\frac{V_{out}}{R_f} = V_{in}\left(\frac{1}{R_f} + \frac{1}{R_i}\right)$$

$$\frac{V_{out}}{V_{in}} = R_f\left(\frac{1}{R_f} + \frac{1}{R_i}\right)$$

G = GAIN

$$G = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_i}$$

IF $G=2$ $\quad \frac{R_f}{R_i} = 1$

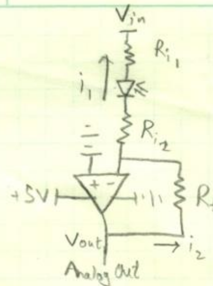
IF $G=4$ $\quad \frac{R_f}{R_i} = 3$

AFTER SOME EXPERIMENTATION, THE RESULTS DID NOT IMPROVE. THE GAIN MERELY GAVE THE SIGNAL A HIGHER OUTPUT BUT THE CHANGE IN VOLTAGE FOR DIFFERENT COLORS DID NOT IMPROVE. NEW CIRCUIT CONFIGURATIONS WILL BE TESTED.

3

COLOR SENSOR

DETECTOR CIRCUIT



$R_f = 680\Omega$

$R_{i_1} = 1k\Omega$

$R_{i_2} = 680\Omega$

ASSUME LITTLE RESISTANCE IN DETECTOR

$$i_2 = \frac{V_{out} - V_{in}}{R_f} \qquad i_1 = \frac{V_{in} - 0}{R_{i_1} + R_{i_2}}$$

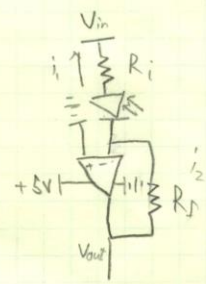
$$\frac{V_{out} - V_{in}}{R_f} = \frac{V_{in} - 0}{R_{i_1} + R_{i_2}}$$

$$\frac{V_{out}}{V_{in}} = R_f\left(\frac{1}{R_f} + \frac{1}{R_{i_1} + R_{i_2}}\right)$$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{680\Omega}{1680\Omega}$$

$$\frac{V_{out}}{V_{in}} = 1.40$$

THIS CIRCUIT DID NOT YIELD DESIRED RESULTS EITHER. THE CIRCUIT WILL BE TRIED AGAIN BUT WITH LESS RESISTORS GOING INTO THE INVERTING INPUT



$R_i = 680\Omega$

$R_f = 680\Omega$

$$i_2 = \frac{V_{out} - V_{in}}{R_f} = i_1 = \frac{V_{in} - 0}{R_i}$$

$$\frac{V_{out}}{V_{in}} = 2$$

THIS CIRCUIT GIVE THE DESIRED RESULTS. IT IS CONCLUDED THE SENSOR CREATED DOES NOT SUPPLY THE ACCURACY NEEDED TO RECOGNIZE A WIDE ARRAY OF COLORS. THE SENSOR CAN DETECT CHANGES IN COLOR ON A WIDER SPECTRUM, BUT NOT FOR WHAT IS NEEDED FOR THIS PROJECT.

APPENDIX W: Sensor Integration

3-8-16 | SENSOR INTEGRATION INTO UR-5 | SAGE THIBODEAU | 1

THE PURPOSE OF THE MOTION SENSORS IS TO RELAY TO THE UR-5 WHETHER SOMETHING HAS DROPPED.

AFTER AN INITIAL TEST AS TO WHETHER THE UR-5 CAN RECEIVE AN ON SIGNAL FROM THE MOTION SENSORS, THE RESULTS WERE NEGATIVE.

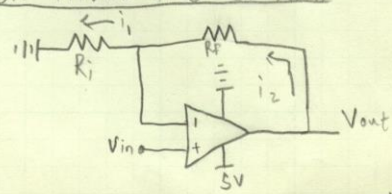
THE REASON IS THAT THE MOTION SENSORS DON'T HAVE A HIGH ENOUGH V_{out}

UR-5 DIGITAL INPUT REQUIREMENTS:
- RANGE: -3V—30V
- OFF: -3V—5V
- ON: 11V—30V

PIR MOTION SENSOR:
- OFF: 0.2mV
- ON: 3.296 V

THE SENSOR OUTPUT MUST BE AMPLIFIED BY ATLEAST 3.34 TO BE READ BY THE UR-5

NON-INVERTING OP-AMP



$$i_2 = \frac{V_{out} - V_{in}}{R_f} \qquad i_1 = \frac{V_{in} - 0}{R_i}$$

(0 ← Ground)

$i_2 = i_1$ BECAUSE NO CURRENT FLOWS ON INVERTING AND NON-INVERTING TERMINALS

$$\frac{V_{out} - V_{in}}{R_f} = \frac{V_{in}}{R_i}$$

$$\frac{V_{out}}{R_f} = V_{in}\left(\frac{1}{R_i} + \frac{1}{R_f}\right)$$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_i}$$

$$3.34 = 1 + \frac{R_f}{R_i}$$

$$\frac{R_f}{R_i} = 2.34$$

$$\frac{R_f}{R_i} = 2.34$$

IF $R_i = 680\ \Omega$

$R_f = 1591.2\ \Omega$

BECAUSE WE NEED A VOLTAGE BETWEEN 11V AND 30V, WE CAN ROUND R_f UP TO $2k\Omega$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{2k\Omega}{680\ \Omega}$$

$$\frac{V_{out}}{V_{in}} = 3.94$$

$V_{out} = 3.94\ V_{in}$, $V_{in} = 3.296\ V$

$V_{out} = 3.94(3.296\ V)$

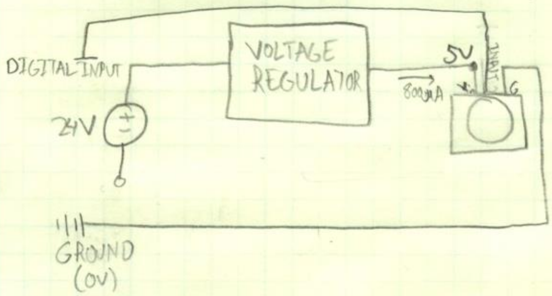
$V_{out} = 13V$

THIS MEETS THE REQUIREMENTS

APPENDIX X: Voltage Regulator

3-5-16 VOLTAGE REGULATOR CIRCUIT SAGE THIBODEAU 1

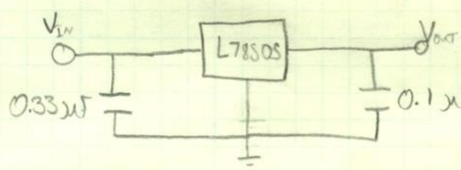
THERE IS A NEED TO REDUCE THE VOLTAGE SUPPLIED BY THE UR-5's ELECTRICAL INTERFACE SO THAT IT CAN SUPPLY THE PROPER VOLTAGE TO SIX PIR MOTION DETECTORS. THE UR-5 SUPPLIES 24V AND UP TO 2A AND THIS NEEDS TO BE REDUCED TO 5V AND 800µA.



THE DESIRED VOLTAGE EXCHANGER IS A LINEAR FIXED VOLTAGE REGULATOR FOR THEIR SIMPLICITY AND THE FACT THAT THE DESIRED OUTPUT VOLTAGE OF 5V WILL NOT VARY.

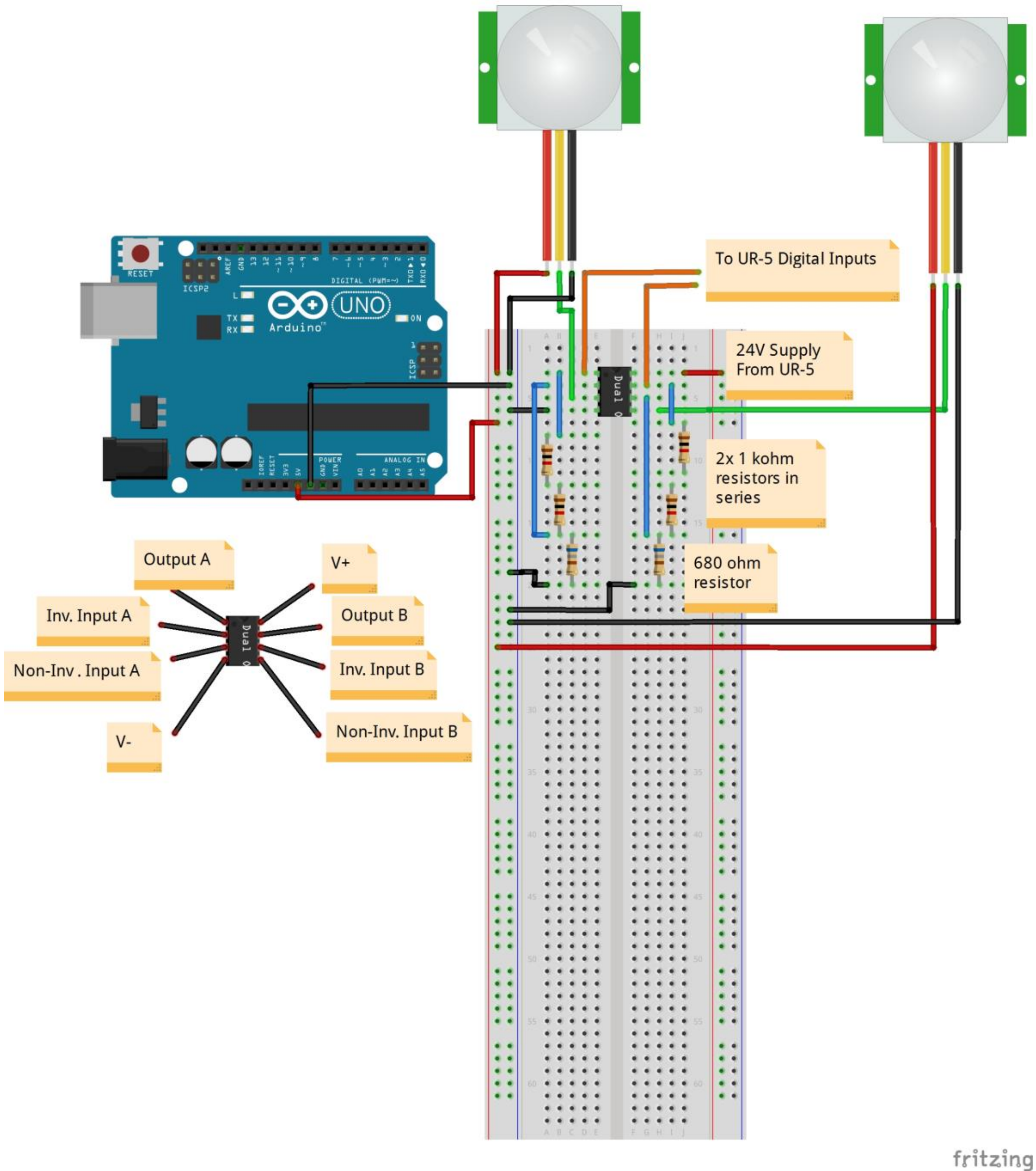
ST MICROELECTRONICS L78S05
CAN HANDLE V_{in} UP TO 35V AND DELIVERS AN OUTPUT OF 5V AND UP TO 2A

MANUFACTURER RECOMMENDED VOLTAGE REGULATOR CIRCUIT.



WHERE THE CAPACITORS ARE USED TO STABALIZE THE OUTPUT VOLTAGE. THEY ARE NOT REQUIRED.

APPENDIX Y: Sensor Connection to Robot



APPENDIX Z: Breakdown of Final Budget

Item	Qty	Cost/Qty	Total Cost
Robot			
UR 5	1	$ 25,600.00	$ 25,600.00
Robotiq Gripper	1	$ 4,320.00	$ 4,320.00
Shipping	1	$ 1,603.00	$ 1,603.00
Mock-Up Material			
2x4x8 Lumber	22	$ 2.57	$ 56.54
Plastic Wing Nut	2	$ 13.14	$ 26.28
Acrylic Tubing	3	$ 36.88	$ 110.64
Wafer Board 4x8x3/8	16	$ 10.75	$ 172.00
Grabber Screws 1.5"	3	$ 4.80	$ 14.40
2x4x12 Lumber	5	$ 4.72	$ 23.60
Acrylic Tubing	3	$ 36.18	$ 108.54
Drawer Slides	1	$ 60.07	$ 60.07
Wing Nut	2	$ 14.74	$ 29.48
4x8x1/8 acrylic Sheet	2	$ 137.02	$ 274.04
1x2x8 Lumber	20	$ 2.57	$ 51.40
Scissors	2	$ 19.52	$ 39.04
Duct Tape & Misc.	1	$ 31.72	$ 31.72
Angled Flashing	1	$ 1.51	$ 1.60
Side Flashing	5	$ 0.99	$ 5.25
Robot Stand			
3.5" schd 40 Pipe	1	$ 20.79	$ 20.79
4" schd 40 Pipe	1	$ 24.05	$ 24.05
1/4x12 12"	1	$ 14.00	$ 14.00
1/4x6" x 6"	1	$ 10.00	$ 10.00
Nuts and Bolts	1	$ 47.98	$ 47.98

Vision System			
Pan Tilt Unit	1	$ 399.95	$ 399.95
Rvision Power Supply	1	$ 300.00	$ 300.00
Rvision Cables	2	$ 200.00	$ 400.00
Composite to VGA Converter	2	$ 46.00	$ 92.00
RCA to BNC Adapter	2	$ 5.00	$ 10.00
RCA to RCA Cable	2	$ 10.00	$ 20.00
RCA to RCA Adapter	2	$ 5.00	$ 10.00
Insight Micro 1100	1	$ 4,484.27	$ 4,484.27
Lens	1	$ 147.14	$ 147.14
Cabling	1	$ 208.93	$ 208.93
Ring Light	1	$ 394.64	$ 394.64
CCS Bracket	1	$ 139.29	$ 139.29
Diffusor Filter	1	$ 92.86	$ 92.86
Micro Trigger Cable	1	$ 88.21	$ 88.21
Donut mount	1	$ 714.00	$ 714.00
Cable Management System	1	$ 726.56	$ 726.56
Ball Bearings (3/4")	2	$ 7.64	$ 15.28
Aluminum Shafts	2	$ 19.57	$ 39.14
Washers	1	$ 9.48	$ 9.48
Rubber Rod	1	$ 3.88	$ 3.88
External Retaining Ring	1	$ 12.30	$ 12.30
Internal Retaining Ring	1	$ 7.03	$ 7.03
C-Clamp (3-D Printed)	1	$ 311.00	$ 311.00
Fiberglass Washer	1	$ 4.26	$ 4.26
Nylon Wingnut	1	$ 9.19	$ 9.19
Nylon Wingnut	1	$ 7.90	$ 7.90
PTFE Flat Washer	1	$ 3.23	$ 3.23
Nylon Fully threaded Rod	1	$ 3.63	$ 3.63
Velcro Cable Tie	2	$ 3.55	$ 7.10
Velcro	1	$ 31.55	$ 31.55
Tie Down Ring	4	$ 4.29	$ 17.16
Unthreaded Spacer	1	$ 4.69	$ 4.69
Aluminum fully threaded rod	1	$ 3.63	$ 3.63
Male Female aluminum	2	$ 2.90	$ 5.80
Cap Screw	1	$ 4.47	$ 4.47
Kevin's Clamp	1	$ 743.00	$ 743.00
Kevin Travel			
Rental Cars	8	$ 150.00	$ 1,200.00

Summary of Budget

Item	Total Cost
Robot / Gripper	$ 31,523.00
Mock- Up Material	$ 1,004.60
Robot Stand	$ 116.82
Vision Systems	$ 9,471.57
Mentor Travel	$ 1,200.00
Total Spent	$ 52,412.34
Total Material Budget	$ 55,000.00
Remaining Budget	$ 2,587.66

Actual Equipment Costs

Item	Total Cost
Robot / Gripper	$ 31,523.00
Machine Vision	$ 8,244.29
Stereo Vision	$ 50,000.00
Rvision	$ 10,000.00
Total	$ 99,767.29

APPENDIX AA: Project Coding

```
// Sage Thibodeau
// ME 4496
// PIR Motion sensor test

// This program is designed to test two PIR motion sensors for
// future use with the Universal Robot UR 5
// The circuit contains:
// two red LEDs (LED1 and LED3)
// one yellow LED (LED2)
// three 1k ohm resistors each in series with an LED
// two PIR Motion Sensors
// One Arduino UNO Microcontroller

// the goal with this test is to not only experiment with the
// capabilities of the sensors, but also to lay out some basic
// code that will help when programming the UR5

// Sensors need about 10 to 40 seconds to calibrate
// set 30 seconds as the calibration time
int calibrationTime = 30;
long unsigned int lowIn; // time where sensor does not detect motion
long unsigned int pause = 5000; // pause before changing sensor state
unsigned long previousMillis = 0; // used to keep track of blink time
const long interval = 1000; // sets an interval of 1 sec
boolean lockLow = true; // decides whether to send message to user or not
boolean takeLowTime; // decides whether to record time of sensor transition
                     // from high to low
int LED2State = LOW; // sets initial LED state to low
int pirPin1 = 2; // motion sensor connected to pin 2
int pirPin2 = 4; // motion sensor connected to pin 4
int LED1 = 8; // LED connected to pin 8
int LED2 = 6; // LED connected to pin 6
int LED3 = 10; // LED connected to pin 10

void setup() {
  Serial.begin(9600); // baud rate
  pinMode(pirPin1,INPUT);
  pinMode(pirPin2,INPUT);// sets the pins connected to motion
                         // sensors as inputs
  pinMode(LED1,OUTPUT);
  pinMode(LED2,OUTPUT);
  pinMode(LED3,OUTPUT); // sets the pins connected to the LEDs
                        // as outputs
  digitalWrite(pirPin1,LOW);
  digitalWrite(pirPin2,LOW); // makes sure no voltage is sent out
```

```
                              // to the motion sensors from the pins
  Serial.print("calibrating sensors");
  for(int i=0; i<calibrationTime; i++)
  {Serial.print(".");
  delay(1000);}
  Serial.println("Done");
  Serial.println("Sensors Active");
  delay(50); // Lets the user know that the sensor are calibrating

  // put your setup code here, to run once:

}

void loop() {
  // if both sensors are activated, let the user know  by lighting up
  // all of the LEDs and record the time they were activated
 if (digitalRead(pirPin1) == HIGH && digitalRead(pirPin2) == HIGH)
{digitalWrite(LED1, HIGH);
  digitalWrite(LED2, HIGH);
  digitalWrite(LED3, HIGH);
  if(lockLow){
    lockLow = false;
    Serial.println("---");
    Serial.print("motion detected by sensors 1 and 2 at ");
    Serial.print(millis()/1000);
    Serial.println("seconds");
    delay(50);}}

   // if only one of the sensors was activated, let the user know which
   // one by lighting up one of the LEDs and record the time of activation
 else if (digitalRead(pirPin1) == HIGH && digitalRead(pirPin2) == LOW)
  {digitalWrite(LED1, HIGH);
  digitalWrite(LED2, HIGH);
  digitalWrite(LED3, LOW);
  if(lockLow){
    lockLow = false;
    Serial.println("---");
    Serial.print("motion detected by sensor 1 at ");
    Serial.print(millis()/1000);
    Serial.println("seconds");
    delay(50);}
    takeLowTime = true;
  }
  else if (digitalRead(pirPin1) == LOW && digitalRead(pirPin2) == HIGH)
  {digitalWrite(LED1, LOW);
```

```
  digitalWrite(LED2, HIGH);
  digitalWrite(LED3, HIGH);
  if(lockLow){
    lockLow = false;
    Serial.println("---");
    Serial.print("motion detected by sensor 2 at ");
    Serial.print(millis()/1000);
    Serial.println("seconds");
    delay(50);}
    takeLowTime = true;
  }
  // If neither sensor is activated then the yellow LED blinks to
  // indicate normal operation
  // If the sensor were previously activated but go inactive after
  // 5 seconds, then the time that motion is no longer detected is
  // recorded
  else(digitalRead(pirPin1) == LOW && digitalRead(pirPin2) == LOW);
  { unsigned long currentMillis = millis();
   if (currentMillis - previousMillis >= interval)
   {previousMillis = currentMillis;
    if (LED2State == LOW)
    { LED2State = HIGH; }
    else{
      LED2State = LOW;}
    if(takeLowTime){
      lowIn = millis();
      takeLowTime = false;
    }
    if(!lockLow && millis() - lowIn > pause)
    {lockLow = true;
    Serial.print("motion ended at ");
    Serial.print(millis()/1000 - pause/1000);
    Serial.println("seconds");
    delay(50);
    }
  digitalWrite(LED2, LED2State);
  digitalWrite(LED1, LOW);
  digitalWrite(LED3, LOW);}
  }}

 //References:

 // Mellis, David A., "Blink Without Delay", Arduino.cc/en/Tutorial, 2005

//Gohlke, Kristian, "PIR Sense Code", Playground.arduino.cc/code/PIRsense,
```

Final Robot Pseudo Code

This write up contains the explicit actions that the robot will take in order to complete the task of loading and unloading the radioactive sample to and from the transfer system and the PFIB.

Loading PFIB

Sample enters room

- Operator activates robot program
- Robot opens gripper
- Robot moves to PFIB door
    - Robot moves gripper between the door handle and door and slides it open.
- Robot moves to transfer station
- Robot opens up transfer system door
    - Door is opened by hooking the handle with the gripper. Gripper remains open
- Robot grabs large sample container out of transfer system
- Container is placed into large holder at transfer station
- Robot closes transfer system door
- Robot moves to overhead position so that the machine vision camera is looking directly down on the top of the container
- Orientation of the container is determined
    - Robot sends digital signal to trigger machine vision snapshot
    - Machine vision uses PatMax pattern matching tool to determine angle that the large container needs to be rotated so that the lid is easy to open for the robot
    - Machine vision sends angle (in radians) to Robot as a string
    - Robot receives the string and converts string value to a integer and stores it as a variable
- Robot moves gripper directly above container so that it is within reach of the container
- Robot removes container from holder and orients it to the desired position
- Container is placed back into the holder in the correct position
- Robot opens container lid
- Robot removes container from holder
- Container is moved over to V-tray at the transfer system where the small container is dumped out
- Robot places large container back into holder
- Robot retrieves small container from V-tray
- Robot moves small container to small holder at transfer station

- Orientation of the container is determined
    - Orientation is determined using the same process as for the large container
- Robot moves gripper directly above container so that it is within reach of the container
- Robot removes container from holder and orients it to the desired position
- Container is placed back into the holder in the correct position
- Robot opens container lid
- Robot removes container from holder
- Container is moved over to V-tray at the transfer system where the sample is dumped out
- Container is placed back into holder
- Robot grabs sample from V-tray and places it directly on transfer table
- Orientation of sample is determined
    - Orientation is determined using the same process as the containers
- Robot grabs sample and carries it over to the PFIB
- Robot slides the sample into the sample slot in the PFIB door
- Robot releases the sample
- Robot closes PFIB door
- The Robot returns to home position

Experimentation is run

Returning to Transfer System

Experimentation is finished, operator activates return program

- Robot opens PFIB door
- Robot moves gripper inside PFIB door to where the sample is held
- Robot grabs and removes sample from the PFIB
- Sample is carried over to the transfer system table
- Sample moved directly over small container
- Robot drops the sample into the small container
- Robot closes small container lid
- Robot grabs small container and removes it from its holder
- Small container is moved directly over large container
- Small container is dropped into large container
- Robot closes large container lid
- Robot opens transfer system door
- Robot removes large container from holder
- Large container is moved inside the transfer system
- Robot closes transfer system door
- Robot moves to home position

Sample returned to transfer system

Dropped Sample/Container Scenario

During operation, there is the possibility that the sample or one of the containers may be dropped. Precautions must be made to make sure that dropped items can be recovered and the experiment can commence. This program describes the automated sequence that will take place if the sample is dropped. However, if there are certain circumstances where the automated sequence cannot successfully recover the dropped item, the operator may take manual control of the robot at any time.

Sample is dropped

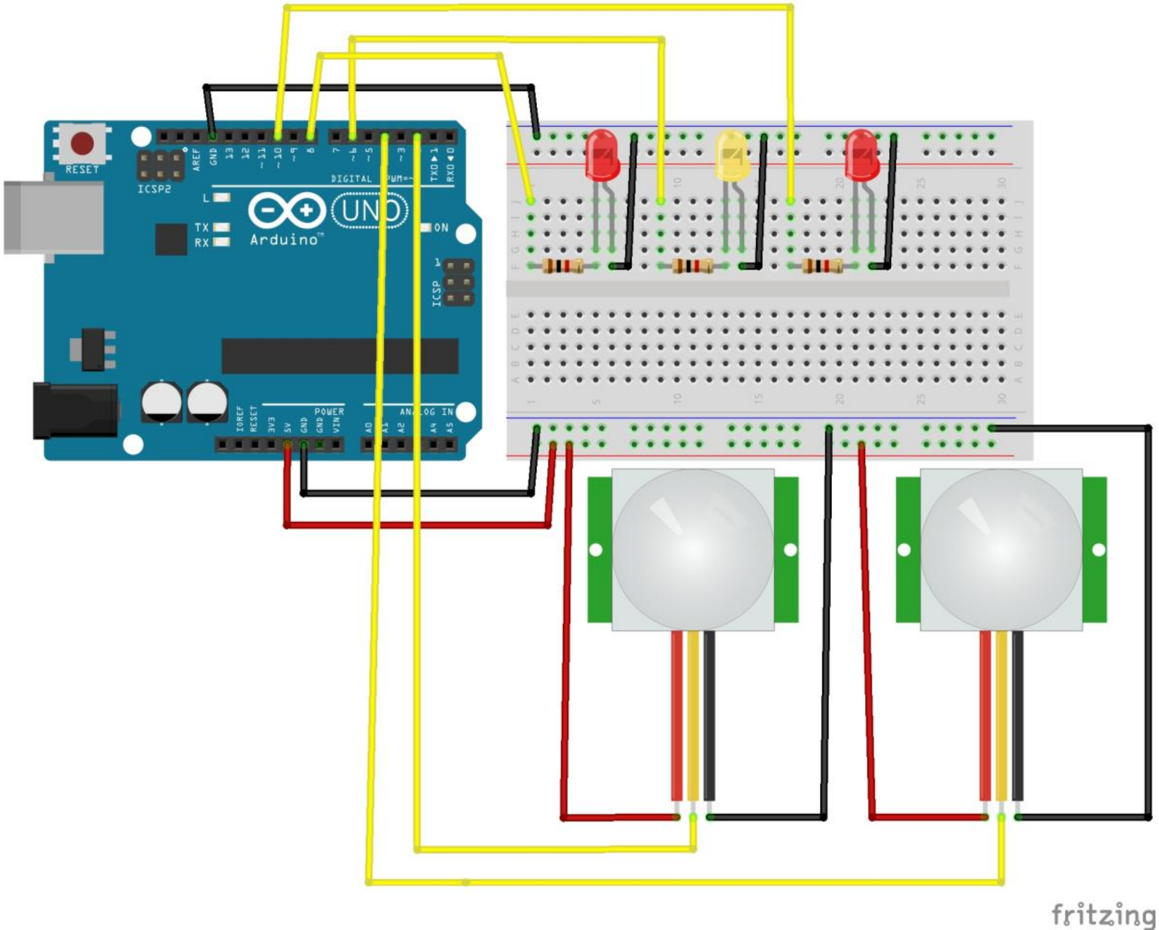
- PIR motion sensor(s) detects motion
    - Sends digital HIGH signal to robot
- Robot arm moves to position of line of sight of the motion sensor triggered
- Robot pans across the edge of the sloped tray
- Machine vision is continuously triggered in search of sample pattern

Machine vision recognizes sample pattern

- Machine vision sends xy coordinates of sample to robot arm
- Robot arm receives coordinates and saves as a variable
- Robot arm uses coordinates to specify designated waypoint to move to in order to pick up the sample
- Gripper picks up sample
- Sample is placed on transfer table
- Robot arm moves machine vision directly above the sample
- Robot triggers machine vision
    - If sample is oriented correctly, program moves to next step
    - If sample is incorrectly oriented, robot reorients sample to correct position
- Operator input requested
    - Should sample be moved to PFIB?
    - Should sample be moved to transfer station?
- Normal operation commences

If a container is dropped, the program will work much the same as dropped sample program. However, the machine vision will recognize that it is a container that has been dropped rather than a sample. The container will be picked up from tray and placed back in its holder in the correct orientation.

Arduino Motion Sensor Circuit



```
/* Sage Thibodeau
 *  2/2/16
 *  Color Tester
 *
 *  This program was used to measure the analog signal of an IR emitter
 *  and detector pair by bouncing IR waves off of different colored
 *  objects and measuring their reflectance.
 */

/*
  AnalogReadSerial
  Reads an analog input on pin 0, prints the result to the serial monitor.
  Graphical representation is available using serial plotter (Tools > Serial
Plotter menu)
  Attach the center pin of a potentiometer to pin A0, and the outside pins to +5V
and ground.

  This example code is in the public domain.
*/

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // print out the value you read:
  Serial.println(sensorValue);
  delay(100);        // delay in between reads for stability
}
```

Machine Vision Program

	A	B	C	D	E	F	G	H	I
0	Image								
1	480.000	0.000	0.000	0.000	1000.000				
2	Trigger	Trigger Del	Trigger Interval (msec	Exposure (msec)	Auto-Expos	Max Expos	Target Brightness		
3	Camera	0	500	8.000	Disable	1000.00	10.000		
4		1.000	0.000	1.000	1.000	0.000			
5	Start Row	Number Of	Light Control Mode	Light Control	Light Enabl	Light Enable 1			
6	0	480	Exposure Controlled	None	0.000	0.000	Time		
7	1.000		0.000	0.000			01/01/1970 00:03:15.000		
8	ism1100	1.000	1.000	0.000	0.000		01/01/1970		
9	Exposur	80.000	100.000	320.000	440.000		00:03:15.000		
10	Focus	80.000	100.000	320.000	440.000	0.000	0.000		
11						0.009	End		
12									
13	Find a PatMax pattern					1	Pattern_1		
14	Image	Row	Col	Angle			Patterns	Calib	
15	Fixture	0.000	0.000	0.000		☐	#ERR		
16	Model	Search				☐ Show Model Region			
17	Patterns	0.000		Trained		43.668	Image	#ERR	
18	Tool Enabl	Include In .	Train	Accept Threshold	Contrast Th	Rotation Tc	Scale Toler	Find Mode	
19	On	☑	Train	50	10	180	10	PatMax	
20	Strict Scori	Ignore Pola	External Retrain	Horizontal Offset	Vertical Off	Timeout	Result	Description	
21	☐	☐	☐	0.000	0.000	5000	#ERR		
22	#ERR	Row	Col	Angle			#ERR	Calib	
23	#ERR	#ERR	#ERR	#ERR	#ERR	#ERR	#ERR	#ERR	
24	#ERR	#ERR	#ERR	#ERR	#ERR	0.000	#ERR	Enabled Status	
25		Tool Pass	Tool Fail	Status	Pass/Fail		0.000	1	
26	☐ Focus	0	1	2	0.000	☑ Show Gr	☑ Show Re	Retrain	
27	1.000	Passes	Failures	Errors	Total	Pattern_1	Plot		
28	Count	0	1	0	1	0.000			#ERR
29							191.376	End	
30			Device	Read					
31			#ERR	#ERR					
32									
33	Find a PatMax pattern					2	Pattern_2		
34	Image	Row	Col	Angle			Patterns	Calib	
35	Fixture	0.000	0.000	0.000		☐	#ERR		
36	Model	Search				☐ Show Model Region			
37	Patterns	0.000		Trained		47.847	Image	#ERR	
38	Tool Enabl	Include In .	Train	Accept Threshold	Contrast Th	Rotation Tc	Scale Toler	Find Mode	
39	On	☑	Train	50	10	180	10	PatMax	
40	Strict Scori	Ignore Pola	External Retrain	Horizontal Offset	Vertical Off	Timeout	Result	Description	
41	☐	☐	☐	0.000	0.000	5000	#ERR		
42	#ERR	Row	Col	Angle			#ERR	Calib	
43	#ERR	#ERR	#ERR	#ERR	#ERR	#ERR	#ERR	#ERR	
44	#ERR	#ERR	#ERR	#ERR	#ERR	0.000	#ERR	Enabled Status	
45		Tool Pass	Tool Fail	Status	Pass/Fail		0.000	1	
46	☐ Focus	0	1	2	0.000	☑ Show Gr	☑ Show Re	Retrain	

47	1.000	Passes	Failures	Errors	Total	Pattern_2	Plot		
48	Count	0	1	0	1	0.000			#ERR
49							191.481	End	
50			Device	Read					
51			#ERR	#ERR					
52									
53	Find a PatMax pattern					3	Pattern_3		
54	Image	Row	Col	Angle			Patterns	Calib	
55	Fixture	0.000	0.000	0.000		☑	Patterns		
56	Model	Search				☐ Show Model Region			
57	Patterns	0.000		Trained		66.225	Image	LatchImage	
58	Tool Enabl	Include In .	Train	Accept Threshold	Contrast Th	Rotation Tc	Scale Toler	Find Mode	
59	On	☑	Train	50	10	180	10	PatMax	
60	Strict Scori	Ignore Pola	External Retrain	Horizontal Offset	Vertical Off	Timeout	Result	Description	
61	☐	☐	☐	0.000	0.000	5000	(256.5,282		
62	Patterns	Row	Col	Angle			#ERR	Calib	
63	Point	282.489	256.496	0.008	Plot	282.489	256.496	0.008	
64	Fixture	Fixture	256.496	282.489	-0.007	99.554	100.006	Enabled Status	
65		Tool Pass	Tool Fail	Status	Pass/Fail		0.000	1	
66	☑ Focus	1	0	1	1.000	☑ Show Gr	☑ Show Re	Retrain	
67	1.000	Passes	Failures	Errors	Total		Plot		
68	Count	0	0	0	0	0.000			0.000
69							269.270	End	
70			Device	Read					
71			Write	(0.000)					
72									

FINAL UR5 PROGRAM

```
 Init Variables
  BeforeStart
    Script: rq_before_start.script
    Script: rq_script.script
    Call SubP_rq_print_driver_version
    rq_gripper_act≔0
    rq_obj_detect≔0
    rq_mov_complete≔0
    rq_pos≔125
    rq_force≔0
    rq_speed≔100
  Robot Program
    Call SubP_rq_activate_and_wait
    Call SubP_rq_set_force
    Call SubP_rq_set_speed
    Call SubP_rq_close_and_wait
    Call SubP_rq_open_and_wait
    MoveJ
      Home
    MoveJ
      Waypoint_1
      Waypoint_2
      Waypoint_4
      Waypoint_5
      Waypoint_6
      Call SubP_rq_move_and_wait
      Waypoint_7
      Call SubP_rq_close_and_wait
    MoveJ
      Waypoint_8
      Call SubP_rq_open_and_wait
      Waypoint_9
      Waypoint_10
      Waypoint_11
      Waypoint_3
      Waypoint_12
      Waypoint_13
    rq_force≔150
    Call SubP_rq_set_force
    Call SubP_rq_close_and_wait
    MoveL
      Waypoint_14
    MoveJ
      Waypoint_15
      Waypoint_16
    MoveL
      Waypoint_17
    Call SubP_rq_open_and_wait
    MoveJ
      Waypoint_36
      Call SubP_rq_close
      Waypoint_37
      Waypoint_38
      Waypoint_40
      Waypoint_41
      Waypoint_42
      Waypoint_39
      Waypoint_27
    MoveJ
      Waypoint_18
      Waypoint_19
      Waypoint_20
    socket_start≔ False
    Set microTRIG=On
    Loop socket_start≟ False

socket_start≔socket_open("169.254.7.2
18",30000)

ReadWaypoint≔socket_read_ascii_float
(1)
    Loop ReadWaypoint[0]≠1

ReadWaypoint≔socket_read_ascii_float
(1)
    Angle≔ReadWaypoint[1]
    socket_close()
    Set microTRIG=Off
    Call SubP_rq_open_and_wait
    MoveJ
      Waypoint_21
    Call SubP_rq_close_and_wait
    MoveL
      Waypoint_22
    Container1_Angl≔p[0,0,0,0,0,Angle]
    MoveL
      Container1_Angl
      Waypoint_23
    Call SubP_rq_open_and_wait
    MoveJ
```

```
Waypoint_24
Call SubP_rq_close_and_wait
MoveJ
  Waypoint_25
  Waypoint_26
MoveP
  open_container
  CircleMove
    Waypoint_28
    Waypoint_29
MoveJ
  Waypoint_30
  Call SubP_rq_open
  Waypoint_31
  Waypoint_32
  Call SubP_rq_close_and_wait
MoveL
  Waypoint_33
MoveJ
  Waypoint_34
  Waypoint_35
  Waypoint_43
  Waypoint_44
  Waypoint_45
  Waypoint_46
  Waypoint_47
MoveL
  Waypoint_48
  Call SubP_rq_open_and_wait
MoveJ
  Waypoint_49
  Waypoint_50
  Waypoint_51
  Call SubP_rq_close_and_wait
  Waypoint_52
  Waypoint_53
MoveL
  Waypoint_54
  Call SubP_rq_open_and_wait
  Waypoint_55
MoveJ
  small_container
socket_start≔ False
Set microTRIG=On
Loop socket_start≟ False

socket_start≔socket_open("169.254.7.2
18",30001)

ReadWaypoint≔socket_read_ascii_float
(1)
       Loop ReadWaypoint[0]≠1

ReadWaypoint≔socket_read_ascii_float
(1)
       Angle≔ReadWaypoint[1]
       socket_close()
       Set microTRIG=Off

Container2_Angl≔p[0,0,0,0,0,Angle]
       MoveJ
         Waypoint_56
         Call SubP_rq_close_and_wait
       MoveL
         Waypoint_57
         Container2_Angl
         Waypoint_58
         Call SubP_rq_open_and_wait
       MoveJ
         Waypoint_59
         Call SubP_rq_close_and_wait
         Waypoint_60
       MoveP
         Waypoint_61
         CircleMove
           Waypoint_62
           Waypoint_63
       MoveJ
         Waypoint_64
         Waypoint_65
         Call SubP_rq_open
         Waypoint_66
         Waypoint_68
         Call SubP_rq_close_and_wait
       MoveL
         Waypoint_67
       MoveJ
         Waypoint_69
         Waypoint
   SubP_rq_activate
     rq_activate()
```

SubP_rq_activate_and_wait
rq_activate_and_wait()
SubP_rq_auto_release_close_and_wait
rq_auto_release_close_and_wait()
SubP_rq_auto_release_open_and_wait
rq_auto_release_open_and_wait()
SubP_rq_close
rq_close()
SubP_rq_close_and_wait
rq_close_and_wait()
SubP_rq_current_pos
rq_current_pos()
SubP_rq_is_gripper_activated
rq_is_gripper_activated()
SubP_rq_is_motion_complete
rq_is_motion_complete()
SubP_rq_is_object_detected
rq_is_object_detected()
SubP_rq_move
rq_move(rq_pos)
SubP_rq_move_and_wait
rq_move_and_wait(rq_pos)
SubP_rq_open
rq_open()
SubP_rq_open_and_wait
rq_open_and_wait()
SubP_rq_print_driver_state
rq_print_driver_state()
SubP_rq_print_fault_code
rq_print_fault_code()
SubP_rq_print_firmware_version
rq_print_firmware_version()
SubP_rq_print_num_cycles
rq_print_num_cycles()
SubP_rq_print_probleme_connection
rq_print_probleme_connection()
SubP_rq_print_serial_number
rq_print_serial_number()
SubP_rq_reset
rq_reset()
SubP_rq_set_force
rq_set_force(rq_force)
SubP_rq_set_speed
rq_set_speed(rq_speed)
SubP_rq_stop
rq_stop()
SubP_rq_print_driver_version
rq_print_driver_version()
SubP_rq_move_21_mm
rq_move(167)
SubP_rq_move_43_mm
rq_move(115)
SubP_rq_move_64_mm
rq_move(65)
SubP_rq_move_21_mm_and_wait
rq_move_and_wait(167)
SubP_rq_move_43_mm_and_wait
rq_move_and_wait(115)
SubP_rq_move_64_mm_and_wait
rq_move_and_wait(65)

APPENDIX BB: SPL Senior Design Scope

SCOPE OF WORK PROPOSAL FOR SPL SENIOR DESIGN PROJECT

IDAHO STATE UNIVERSITY - SENIOR PROJECT DESIGN I, II

DRAFT

Participants: Larinda Nichols, Nuclear and Mechanical Engineering
Cody Race, Nuclear and Mechanical Engineering
Jerron Berrett, Mechanical Engineering
Sage Thibodeau, Mechanical Engineering

INL Mentors: Kevin M. Croft, Senior Advisory Engineer
Mitchell K. Meyer, Director of INL Nuclear Fuels and Materials

Project: Sample Preparation Laboratory Teleoperations

Summary: The Idaho State University (ISU) Senior Project Design course is a two-semester, 32 week requirement for all students graduating with an ISU Engineering degree. This course will serve to provide students with real-life exposure to the design, analysis and implementation process that accompanies each engineering project. The design team for Idaho National Laboratory's new Sample Preparation Laboratory (SPL) has requested teleoperations for loading and unloading radioactive samples for examination by several highly-specialized pieces of equipment. An opportunity has been proposed for the Senior Design participants listed above to aid in the research, testing, and implementation of the teleoperation equipment under the direction of Kevin M. Croft.

Benefits: Student exposure to real work environment.
Opportunity for students to contribute to new technology.
INL recruiting opportunity and sponsorship of ISU Engineering Department.

Assumptions: Outside funding for non-labor costs (mock-up and procurement of equipment) to be provided by INL. Funding for any labor to be determined.

Individual team member responsibilities to be assigned by September 7, 2015.

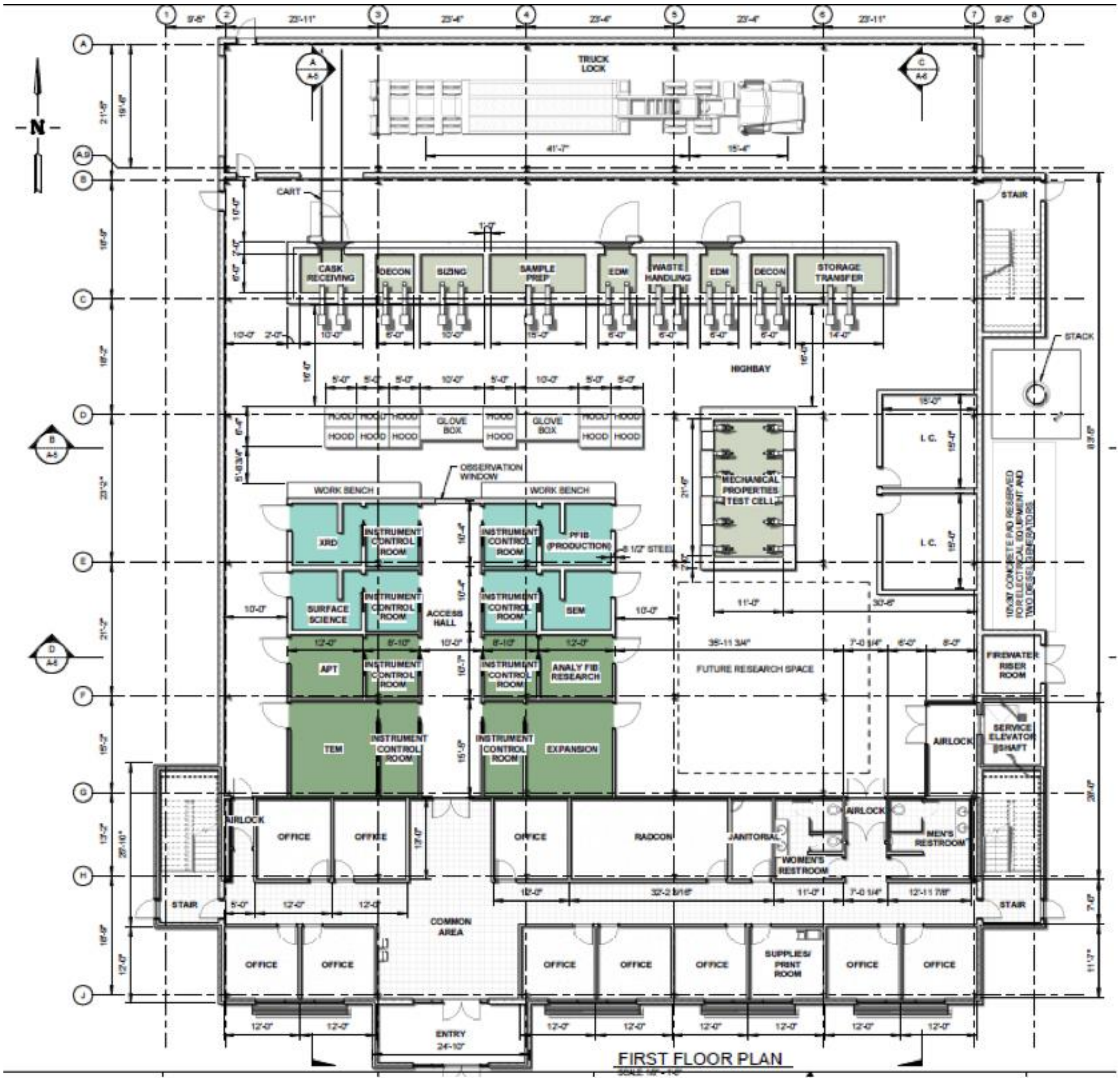
PROJECT TIMELINE AND ESTIMATED PARTICIPATION

Hours Per Week Per Teammate	Total Number of Weeks	Total Number of Project Hours Per Teammate	Number of Team Members	Total Number of Project Hours
5	32	160	4	640

FALL SEMESTER: DESIGN/ANALYSIS
1. Written project proposal.
2. Assign individual roles.
3. Conceptual design process.
4. Analysis of possible solutions.
5. Converge on single design.
6. Focus timeline and anticipated outcome.

SPRING SEMESTER: IMPLEMENTATION
1. Procure equipment.
2. Preliminary testing and problem solving.
3. Adjustments to original design.
4. Mock-up of final environment.
5. Project analysis and modifications to final design.
6. Implementation and/or final outcome report.

APPENDIX CC: SPL Facility Layout



APPENDIX DD: Equipment Recommendation to INL

Idaho State
UNIVERSITY

IDAHO NATIONAL LABORATORY
SAMPLE PREPARATION LABORATORY
(Senior Design Project)

SPL Equipment Recommendation

1/20/2016

ISU Senior Design Students/INL Interns
Cody Race, Larinda Nichols (ME,NE)
Sage Thibodeau, Jerron Berrett (ME)

INL Mentor
Kevin M. Croft (ME)

Department of Mechanical and Nuclear Engineering
ME-4496 Senior Project Design

PROJECT REQUIREMENTS

The ISU Sample Preparation Laboratory Team (SPLT) has been asked to assist the Idaho National Lab (INL) in developing a robotic arm system capable of loading and unloading radioactive metallurgical samples containing beta-gamma emitting material from a pneumatic transport system to examination equipment (such as a Plasma Focused Ion Beam (PFIB) instrument) remotely in their proposed SPL facility. Major factors influencing the choice of robotic arm make and model are listed below:

a. Must be commercially available,
b. Size of robotic arm (robot must be capable of performing tasks without causing interference to equipment within its reach),
c. Axes of motion (degrees of freedom) which addresses flexibility to perform work,
d. Accuracy and repeatability,
e. Placement relative to room size, pneumatic transfer system, and instrument (with recommended clearances around instrument),
f. Ability to remotely open/close pneumatic sample carriers,
g. Ability to retrieve dropped sample, and
h. Purchase and maintenance costs.

PROJECT ASSUMPTIONS

In addition to the project requirements listed above, the following assumptions were also made as part of the decision making process:

a. Payload for this application is negligible
b. All four instrumentation cells will employ the same system
c. Robotic arm may be mounted in a stationary position or on a moveable track.
d. Robotic equipment considered for other non-instrument areas (such as the Materials Properties Test Cell) of SPL are independent of this study, and
e. Processes are programmed. Exceptions may occur where commercially provided teleoperation features of robot may be used for robot program teaching or picking up of dropped sample.

PRODUCT LINE

A variety of robotic arms are currently available on the market; however, the specific nature of this task has led the team to a company called Universal Robots of Denmark (they have significant distribution in the United States). Reasons for this decision include accuracy, precision, cost, reliability, ease of programming and their reach radius. Universal Robots also allow easy integration of a customized, versatile two-finger gripper, supplied by the company Robotiq. The gripper adds extra reach of up to 8 inches and can handle loads of up to 11 lbs. Universal Robots offers a line of robotic arms with proportional specifications based upon reach and payload.

MODEL	PAYLOAD	WEIGHT	REACH	FOOTPRINT	COST
UR-3	6.6 lbs.	24.3 lbs.	19.7 in.	4.6 in.	$23,000
UR-5	11 lbs.	40.6 lbs.	33.5 in.	5.9 in.	$35,000
UR-10	22 lbs.	63.7 lbs.	51.2 in.	7.5 in.	$45,000

The benefits of using a UR-3 model for this application include less initial expense and smaller footprint. However, the team has determined that the UR-3 does not provide adequate reach for loading and unloading samples. It also does not allow for a large enough clearance space for the necessary instrumentation access.

The UR-5, sample room layout in Appendix (Figure 1), provides a larger reach, but is compact enough to allow for potentially more safety features such as a full enclosure in the case of a dropped sample. Additionally, the payload is almost double that of the UR-3. The UR-10, sample room layout in Appendix (Figure 2), is likewise attractive for its longer reach and higher payload which allows for future capabilities should the need arise. It is understood, however, that this additional reach could prove problematic if a sample is dropped during transfer. This is due to the larger area that the sample could potentially be dropped.

All models provide the accuracy and repeatability required for the application; therefore, the final decision is based on robot reach and payload, taking into consideration area to drop the sample and instrument access. As a result, the team constructed a simple and inexpensive three-dimensional mock-up, as seen in Appendix (Figure 3), of an instrumentation cell to compare the performance of each robot relative to the given workspace. This mock-up provided a life like, realistic visual for the team to determine the best position for the instrumentation (PFIB in this case) and the other components needed. A mock-up of the UR-3, UR-5 and UR-10 were inexpensively constructed to be used in the mock-up of the instrumentation cell. These were used to determine a relative position, both in the x-y plane and the z direction (height), that would allow for the proper procedure to be done and the possible limits of each. The UR-5 and UR-10 were deemed sufficient for further exploration and a computer simulation was prepared in SolidWorks to identify the best possible solution.

RECOMMENDATION

After simulating the maneuverability of the UR-5 and UR-10 in a 3D mockup of the sample cell and weighing the benefits and weaknesses of both robots, the team would like to make the recommendation of using the UR-5 in the Sample Preparation Laboratory instrumentation cells. The UR-5 is commercially available. The size of the robotic arm is capable of performing tasks without causing interference to the equipment. It can move in all desired positions due to its six degrees of freedom, allowing maximum maneuverability. The UR-5 can be placed in such a way that it meets the equipment space requirements based on the recommended maintenance space from the PFIB manual and requirements discussed with Dean while looking at the PFIB. A benefit discussed earlier that the UR-5 has over the UR-10 is a potential for total enclosure that would allow complete assurance that the sample will always be able to be obtained remotely or teleoperated by the robotic arm. The UR-5 and UR-10 differ when it comes to cost and risk of losing a dropped sample. The UR-5 has a cost of $35,000, the UR-10 costs $45,000, which could potentially bring a savings of around $40,000 if UR-5's are used in the three neighboring cells running similar operations. The smaller reach of the UR-5 decreases the radius in which a dropped sample may escape in the cell, but is still capable of maintaining adequate distance between the instrumentation and pneumatic transfer station for maintenance and walking paths. The smaller radius in which the sample can be dropped is very beneficial in making sure the sample does not get lost in the cell as well as keeping the dropped sample recovery system simple and compact. A downside to UR-5 is the potential for longer maintenance time removing safety barriers. This recommendation is based on the assumption that the dropped sample tray is at the base of the robotic arm which is level with the top of the PFIB table.

SUGGESTED ALTERNATIVE

The UR-10 is considered a viable option for the SPL instrumentation cells because it can also carry out the same tasks as the UR-5, albeit its size and reach envelope are considered to be larger than required for this application. The UR-10 is less attractive when considering cost and the potential for a dropped sample. Despite the UR-10 having a longer reach, which could allow for more space for maintenance and possible future applications, it also increases the radius in which a dropped sample could be lost in the cell. The ability to be fully enclosed is also not reasonable due to the size. The benefit of having a larger reach does not counteract the danger of having a larger radius for a dropped sample. The attachable gripper is also only rated for 11 lbs while the UR-10 is rated for 22 lbs, so the only benefit gained from the UR-10 would be the reach. For this application payload is assumed to be negligible. The UR-5 is deemed to be a safer option than the UR-10.

CONCLUSION

The team recommends that the UR-5 be utilized in SPL instrumentation cells rather than the UR-10 because it can carry out all of the tasks that the UR-10 can while having a lower cost and a reduced radius for a dropped sample. The UR-5 still has enough reach to carry out all tasks required of it and can also be worked around during maintenance. It also creates a potential for more safety barriers to be added.

APPENDIX

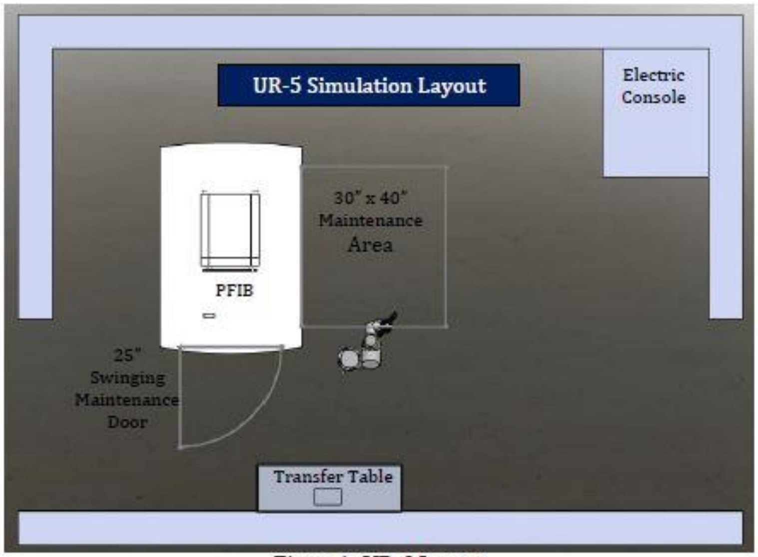


Figure 1: UR-5 Layout

The UR-5 layout above is the used layout for the simulation created in SolidWorks. The position of the robot was determined from the lab mock-up. The current height is the same as the PFIB counter. It is located 12 inches to the right of the PFIB and four inches down.

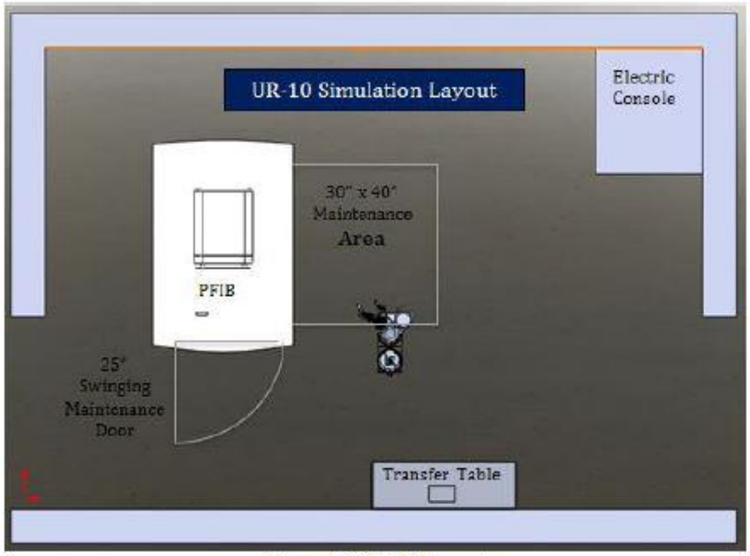


Figure 2: UR-10 Layout

The UR-10 layout above is the used layout for the simulation created in SolidWorks. The position of the robot was determined from the lab mock-up. The current height is 12 inches off the ground. It is located 30 inches to the right of the PFIB and four inches down.

Figure 3: Lab Mock-up of Instrumentation Cell w/ PFIB
The lab mock-up allowed for the visual and initial testing of the robotic arm sizes. The relative position to allow for best results were tested using the mock-up as well as the limits for all robot sizes.

APPENDIX EE: Product Information

PLEXIGLAS® Acrylic Sheet

Ultraviolet transmittance

Plexiglas sheet absorbs short wavelength ultraviolet (UV) energy, but transmits most of the long wavelength UV (those wavelengths just short of the visible region), Figure 3.

This UV stability gives Plexiglas sheet superb weatherability and makes it the logical choice for outdoor and artificial lighting applications.

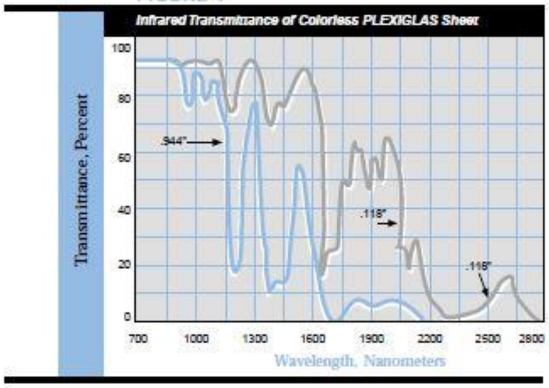
The absence of visible changes in Plexiglas sheet after prolonged outdoor or artificial light exposure means that no change has taken place in the spectrophotometric characteristics of the material in the ultraviolet and visible ranges. Plexiglas sheet exhibits an increase in UV absorbance caused by sunlight. Most of the drop in UV transmittance of Plexiglas sheet takes place in the first two years. Absolutely no change occurs in the spectrophotometric curves of these exposed samples between 5 and 10 years outdoors.

Colorless Plexiglas sheet exhibits the same excellent resistance to discoloration when exposed for 20 years or more to constantly lit fluorescent lamps, even when the Plexiglas sheet is only two inches from the lamp.

Some applications, such as document preservation, call for a filter material that absorbs more UV energy than ordinary glass without absorbing visible light. Plexiglas G UF-3 and Plexiglas MC UF-5 acrylic sheet absorb 98% of all UV rays, as well as some visible light. Plexiglas G UF-4, developed for mercury vapor lighting applications, can also be used as a protective shield. Plexiglas G UF-4 sheet does transmit slightly more UV energy than Plexiglas G UF-3 and Plexiglas MC UF-5 sheet.

FIGURE 4

Infrared Transmittance of Colorless PLEXIGLAS Sheet



Infrared transmittance

Colorless Plexiglas sheet transmits most of the invisible near-infrared energy in the 700 to 2800 nanometer region, but it also absorbs certain bands as shown in Figure 4. The curves for 0.118" and 0.944" thick colorless Plexiglas sheet show that near-infrared transmittance depends on thickness, decreasing logarithmically as thickness increases.

At infrared wavelengths longer than 2800 nanometers and as long as 25000 nanometers, and in thicknesses greater than 0.118", colorless Plexiglas sheet is entirely opaque. At thicknesses less than 0.118", Plexiglas sheet transmits small amounts of infrared energy at certain wavelengths within this region. All standard formulations of colorless Plexiglas sheet have the same general infrared transmittance characteristics.

Sensitive instruments confirm that weathering produces no change in the infrared transmittance characteristics of Plexiglas sheet.

Plexiglas G 3143 custom-colored sheet selectively transmits infrared light. Applications for this material include remote control devices, laser lenses, and heat sensors.

X-ray transmittance

Colorless Plexiglas sheet readily transmits X-rays in all ordinary thicknesses. Plexiglas sheet has essentially the same X-ray absorption coefficient as water. X-ray photographs can be taken of knitting bone fractures without removing the acrylic splints.

Radio frequency transmittance

Most formulations of colorless Plexiglas sheet readily transmit standard broadcast and television waves as well as most radar bands.

High-energy radiation

Although Plexiglas sheet possesses unusual resistance to discoloration from exposure to all ordinary light sources, special sources that emit a combination of

TABLE 8: Noise Reduction Values for PLEXIGLAS Sheet

(Test panels were 75" x 100")

Frequency spectrum of noise source	Approximate noise reduction - dB(A) Sheet thickness (in)				
	.118* (3mm)	.236 (6mm)	.472 (12mm)	.944 (24mm)	double glazed**
Low frequencies predominant	15	21	26	30	34
Flat frequency spectrum	25	29	33	35	38
High frequencies predominant	28	31	34	36	40

* Estimated from measurements of .236", .472", and .944" sheet.
** 0.236" Plexiglas sheet, air space, 0.177" Plexiglas sheet.

TABLE 9: STC Noise Ratings of PLEXIGLAS Sheet

Construction thickness	STC
Plexiglas sheet (0.118")*	25
Plexiglas sheet (0.236")	29
Plexiglas sheet (0.472")	33
Plexiglas sheet (0.944")	35
Plexiglas sheet [(0.236") air space (0.177")]	38

*Estimated from measurements of .236", .472", and .944" sheet.

intense, high-energy radiation plus visible light may in time discolor and even physically degrade Plexiglas sheet.

Under normal exposure conditions, visible light and UV radiation do not affect the optical properties of Plexiglas sheet, but UV radiation between 280 and 400 nanometers, if sufficiently intense or persistent, will cause slight yellowing. Light sources that may produce this type of energy include sunlamps and mercury vapor lamps.

Discoloration induced by the high UV emissions of some mercury vapor lamps is best resisted by the special colorless formulation, Plexiglas G UF-4 sheet.

Germicidal or sterilizing radiation (approximately 260 nanometers) attacks all types of Plexiglas sheet and most other organic materials. This short wavelength UV radiation has a very high energy content capable of physically damaging Plexiglas sheet. For this reason, acrylic parts should be shielded from direct exposure to radiation produced by germicidal lamps such as those used in vending machines.

High energy ionizing radiation of the type encountered in outer space or in nuclear experiments is usually harmful to Plexiglas sheet, causing discoloration, physical deterioration, or both. The specific reaction of Plexiglas sheet closely depends on the nature of the radiation, its intensity and duration. The behavior of acrylic sheet and other plastics on exposure to ionizing radiation has been discussed in the scientific literature.

Nuclear radiation transmittance

Colorless Plexiglas G sheet has the following nuclear transmittance characteristics:

- ***Alpha rays***—Generally opaque, exhibiting essentially 100% absorption at all thicknesses.
- ***Beta rays***—Essentially opaque at thicknesses of 0.334" or more.
- ***Gamma rays***—Transparent to gamma rays in all ordinary thicknesses. Colorless Plexiglas sheet has about the same gamma ray absorption coefficient as water; however, high dosage and intensity, as is common in sterilizing, may

TABLE 10: Comparison of Noise Reduction Characteristics of PLEXIGLAS Sheet With Other Materials

Construction material thickness	Approximate noise reduction*- dB(A)
Plexiglas sheet (0.118")	25
Plexiglas sheet (0.236")	29
Plexiglas sheet (0.472")	33
Plexiglas sheet (0.944")	35
Double glazed Plexiglas sheet	38
Glass (1/8")	25
Glass (1/4")	27
Plywood (1")	26
Steel (1/8")	37
Sheet lead (1/16")	38
Wood stud partition	38

**Noise reduction obtained in enclosures depends on the completeness of the enclosure, tightness of joints, etc. The above dB(A) noise reductions were obtained in a completely enclosed, tightly joined structure. These conditions are seldom achieved in the real world; however, even under more realistic conditions, the use of Plexiglas sheet barriers can reduce noise levels enough to protect against heavy damage. The main purpose of this Table is to indicate the relative noise reduction capabilities of commonly used materials in terms of dB(A).*

WHERE INNOVATION MEETS AUTOMATION

ROBOTIC ACCESSORIES

Robot Pedestals

Pedestals
Self-contained pedestal mounting for UR robot with ergonomic mounting for convenient use of the robot teach pendant.

Optional tool trays can be added to increase functionality. Various heights available. Typical uses include any application requiring the robot to be mounted with limited footprint.

Part Numbers

SA0107799- UR 5 pedestal, 36"

SA0107230- UR 5 pedestal, 42.3"

SA0107803- UR 10 pedestal, 36"

SA0107202- UR 10 pedestal, 42.3"

SA0107196- UR pedestal ERGO arm for teach pendant

SA0107195- UR pedestal tool holder

Specifications

Material: Aluminum
Available Heights: 24", 36", 42.3"
Weight: Varies
Dimensional Drawings: back page

ONLINE RESOURCES

- https://youtu.be/tNMvBuh6SYA
- https://youtu.be/Z6mzSm2QWaU
- https://youtu.be/1oJySJup6z8
- UR Workstation 3D Model
- UR "T" Slot Table 3D Model

ISO 9001 CERTIFIED

We Can Help You

Olympus Controls is an engineering services company that specializes in machine automation. Olympus is known throughout the industry for assisting clients with the ideation of unique and innovative automation solutions. Olympus collaborates with customers to deliver mechanical, electrical and software products that bring solution concepts to reality.

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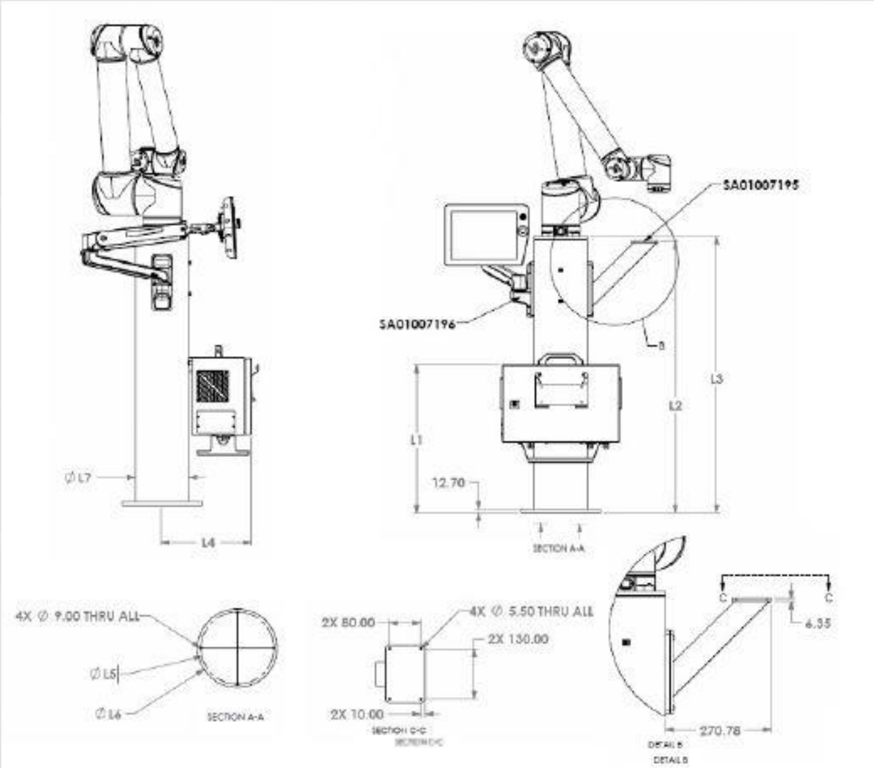
www.olympus-controls.com

Technical Specifications: Pedestal



	UR 5			UR 10	
	SA0107799	SA0107230		SA0107803	SA0107202
L1	502.7	602.7		502.7	602.7
L2	888.3	1048.5		888.3	1054.8
L3	914.4	1074.6		914.4	1074.6
L4	314.9	314.9		340.3	340.3
L5	240	240		280	280
L6	270	270		304.8	304.8
L7	152.4	152.4		203.2	203.2

We Can Help You

Olympus Controls is an Engineering Services company that specializes in Machine Automation. We help our clients with the ideation of unique and innovative solutions then we collaborate with them to deliver the mechanical, electrical and software pieces that take their solution from concept to reality.

info@olympus-controls.com

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General Specifications

The following sections list general specifications for the In-Sight Micro vision systems.

Table 3-1: In-Sight Micro Vision System Specifications

Specification		In-Sight 1020/1050	In-Sight 1100/1110	In-Sight 1100C	In-Sight 1400/1410	In-Sight 1400C	In-Sight 1403/1413	In-Sight 1403C
Minimum Firmware Requirement		In-Sight version 4.1.0		In-Sight version 4.3.0	In-Sight version 4.1.0	In-Sight version 4.3.0	In-Sight version 4.1.0	In-Sight version 4.3.0
Memory	**Job/Program**	64MB non-volatile flash memory; unlimited storage via remote network device.						
	Image Processing	128MB						
Image	**Sensor**	1/3-inch CCD					1/1.8-inch CCD	
	Sensor Properties	5.92mm diagonal, 7.4 x 7.4µm sq. pixels					8.8mm diagonal, 4.4 x 4.4µm sq. pixels	
	Resolution (pixels)	640 x 480					1600 x 1200	
	Electronic Shutter Speed	16µs to 1000ms					27µs to 1000ms	
	Acquisition[1]	Rapid reset, progressive scan, full-frame integration.						
		256 grey levels (8 bits/pixel)		24 bit color	256 grey levels (8 bits/pixel)	24 bit color	256 grey levels (8 bits/pixel)	24 bit color
		Gain/Offset controlled by software.						
		60 full frames per second		57 full frames per second	60 full frames per second	58 full frames per second	14 full frames per second	7 full frames per second
	Lens Type	CS-mount and C-mount (with 5mm extension, included).						
	CCD Alignment Variability[2]	±0.127mm (0.005in), (both x and y) from lens C-mount axis to center of imager.						

SEE HP™

Pan Tilt Assembly | Single Sensor | Color or Thermal

2016 Data Sheet

RVision

Product Overview

The RVision SEE HP™ pan tilt assembly is the original member of the RVision family of rugged and compact cameras. Manufactured from Aluminum and engineered to exacting standards, it is ideally suited for deployment in harsh environmental conditions. Motors driving the pan/tilt functions provide near-silent performance with improved repeatability for presets and go-to targets. The integrated slip ring allows for continuous 360° pan rotation.

The SEE HP™ is available with the RVision BigFoot™ Mil-Spec connection or with the RVision QuickConnect™ cable assembly mount, both rugged for quick installations in tactical or mobile solutions. The BigFoot™ and QuickConnect™ systems are both compatible with many other mounts, cables and accessories available for integration in the RVision camera family.

The SEE HP™ employs SD color video and can be fitted with a thermal imager as well. Thermal options are available with either an uncooled 320x240 or 640 x 480 Vanadium Oxide Sensor and 3 standard lens options (35mm, 50mm, 60mm).

Pan Range	Continuous		
Tilt Range	240°		
Pan Speed	0.1°/s Min. to 120°/s Max		
Tilt Speed	0.1°/s Min. to 120°/s Max.		
Control Interface/Protocol	RS232, RS422/485 - RVision, Pelco-D, Pelco D Enhanced		
Color Sensor	550TVL, 380K Pixels		
Color Sensor Zoom	36X Optical, 12X Digital, 57.8°-1.7° HFOV		
Color Sensitivity	0.1 lx Color, 0.01 lx NIR (1/4s)		
Thermal Sensor Primary Option	640x480, 17 micron, Vanadium Oxide, 50mm		
Power Draw, w/heaters, without	Power-on Peak	84 W	36 W
	Staring – no motion	60 W	12 W
	All Motor Moving	84 W	36 W
Presets	100		
Weight	10.5 lbs. with BigFoot™		
Housing Material	Aluminum		
Voltage	12-30 VDC		
Operating Temperature	-40°C to +70°C, with heaters		
Storage Temperature	-40°C to +75°C		
Mounting	BigFoot™ or QuickConnect™		

For further information please contact:

3033 Fifth Ave, Suite 400
San Diego, CA 92103
T. 619.233.1403
F. 619.233.1423

APPENDIX FF: Equipment Quotes

Olympus Controls
Your Local Automation Partner

Corporate Headquarters
18280 SW 108th Ave.
Tualatin, OR 97062
Ph: 503-582-8100
Fax: 503-582-9477

Gulf Division
703 Main St.
Lake Dallas, TX 75065
Ph: 940-565-9411
Fax: 940-279-1131

Bay Division
47603 Lakeview Blvd.
Fremont, CA 94538
Ph: 510-565-7525
Fax: 510-952-3170

PACIFIC ID
1400 Talbot Rd. South Ste. 400
Renton, WA 98055
Ph: 425-430-0044
Fax: 425-430-9724

Northwest Division
Portland • Vancouver • Tacoma • Seattle • Spokane • Boise
Gulf Division
Dallas • Austin • Houston • El Paso • Tulsa • Little Rock
Bay Division
Fremont • Livermore • Sacramento

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CUSTOMER

Kevin Croft
Battelle Energy Alliance - Idaho Fall
Po Box 1625
Idaho Falls, ID 83415
kevin.croft@inl.gov

QUOTATION

Quote #: 10472
Quote Date: 9/15/2015
Expiration Date: 10/15/2015
Sales Engineer: Jason B Brickner
Quoted By: Sam Gemmet

TERMS & CONDITIONS

Payment Terms:
Availability:
Freight on Board: FOB Factory

#	Part Number	Description	Manufacturer	Unit	Price	X	Total
1		**UR3 Robot and Shipping**					
2	UR3	110103 - 6-axis robot arm with a working radius of 500 mm / 19.7 in, 3kg Payload	Universal Robots	EA	$20,000.00	1.00	$20,000.00
3	FRT_UR3	UR3 Inbound Shipping	Olympus Controls	EA	$1,257.00	1.00	$1,257.00
4		**UR5 Robot and Shipping**					
5	UR5 AE3	110105 - 6-axis robot arm with a working radius of 850 mm / 33.5 in, 5kg Payload	Universal Robots	EA	$25,600.00	1.00	$25,600.00
6	FRT_UR5	UR5 Inbound Shipping	Olympus Controls	EA	$1,257.00	1.00	$1,257.00
7		**UR10 Robot and Shipping**					
8	UR10 AE3	110110 - 6-axis robot arm with a working radius of 1300 mm / 51.2 in, 10kg Payload	Universal Robots	EA	$34,300.00	1.00	$34,300.00
9	FRT_UR10	UR10 Inbound Shipping	Olympus Controls	EA	$1,603.00	1.00	$1,603.00
10		**Robotiq 2-Finger Gripper**					
11	AGC-UR-KIT-002	2-Finger 85 Adaptive Gripper kit for Universal Robots - Included: - - 1 x Basic Gripper Unit - - 2 x Flat Silicone Fingertips - - 1 x End Effector Coupling for Bolt Pattern ISO 9409-1-50-4- - M6 (with 1 m Pigtail Cable) - - 1 x 10 m Robotiq Device Cable - - 1 x USB to RS485 Adapter - - 1 x Screw Kit for Fixing End Effector Coupling on UR Robots - - 1 x USB Stick - Software package available at support.robotiq.com	Robotiq	EA	$4,320.00	1.00	$4,320.00

Line	Quantity	Product		Ships	Unit price	Total	Delete
1	10 packs	20585T24	Corrugated Sheet, 36" Width x 48" Length, Cardboard, packs of 5 **Order quantity totals 50 - 10 Packs of 5 Each.**	today (from our Chicago warehouse) Need this sooner?	$11.21 pack	112.10	
2	2 each	76305A11	Hand-Held Dispensers for Packaging Tape, Standard, 2" Maximum Tape Width	today	18.04 each	36.08	
3	6 rolls	76255A17	Packaging Tape, General Purpose, 2" Wide x 110 Yard, .0025" Thick, Clear, packs of 36	today	5.68 roll	34.08	
4	6 each	6641T12	Coaxial Cord, BNC Male x BNC Male, Audio/Video, 6' Long, 75 Ohms	today	7.33 each	43.98	
5	2 each	71115K11	BNC Coaxial Cable Connector, Tee, Female x Female x Female, 75 Ohms	today	3.14 each	6.28	
6	1 each	9444T11	T-Square with Aluminum Head, 22" Head Length, 48" Blade Length	today	18.02 each	18.02	
7	2 each	1908A15	Wood Yardstick	today	3.47 each	6.94	
8	2 sets	1661T53	Firm-Tip Ink Marker, Fine Tip, 4 Color Set	today	6.69 set	13.38	
9	3 each	3768A12	High Leverage Lightweight Stainless Steel Scissors, 7-1/4" Overall Length, 1-3/4" Long Cut, Titanium Nitride Coated	today	8.24 each	8.24	
10	1 each	3438A15	Lightweight Titanium Scissors, Standard Duty, Offset, 9" Overall Length, 4" Cut Length	today	13.10 each	26.20	
11							
	ADD ? Paste products and quantities			Merchandise total		$305.30	

Idaho State UNIVERSITY

Sage Thibodeau <thibsage@isu.edu>

Robotiq quote request

3 messages

Alexandre pare <alexandre.pare@robotiq.com> Fri, Nov 20, 2015 at 8:14 AM
Reply-To: alexandre.pare@robotiq.com
To: Sage Thibodeau <thibsage@isu.edu>

Hi Sage,
I got your quote request online for our 2 finger grippers for Universal Robot.

Price for the 2F85 gripper Universal Bundle kit is $4,800 and for the 2F140 is $4,975.

These include all you need to install the gripper on UR and program it. It also includes programming templates to help you get started.

For your design project do you simply need to design the concept and get pricing or will you eventually physically do the project. If so, when do you expect starting the project?

Best regards

Alexandre Pare
Application Engineer
1-888-ROBOTIQ (762-6847) ext. 125
1-418-209-7638 (Cell)
1-418-380-2788 ext. 125 - outside USA and Canada

alexandre.pare@robotiq.com

www.robotiq.com

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ROBOTIQ

Sage Thibodeau <thibsage@isu.edu> Fri, Nov 20, 2015 at 8:35 AM
To: alexandre.pare@robotiq.com

Alexandre,

Thank you for getting back to me. My team and I are looking to actually build this system. It's just a matter of when we get the funding which may not be until January or into the spring.

Thanks again,

Sage Thibodeau
[Quoted text hidden]

Alexandre Paré <alexandre.pare@robotiq.com> **Mon, Nov 23, 2015 at 2:15 PM**
To: Sage Thibodeau <thibsage@isu.edu>

Hi Sage,
sounds good.
Thanks for the feedback.
In the meantime feel free to check our support website for more technical information and some CAD Drawings!

Best regards

Alexandre Pare
Application Engineer
1-888-ROBOTIQ (762-6847) ext. 125
1-418-209-7638 (Cell)
1-418-380-2788 ext. 125 - outside USA and Canada

alexandre.pare@robotiq.com
www.robotiq.com

ROBOTIQ

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APPENDIX GG: Project Correspondence

TO:	Olympus Controls
FROM:	Kevin M. Croft, Idaho National Laboratory
SUBJECT:	PURCHASE OF UNIVERAL ROBOT UR-5 AND ROBOTIQ 2-FINGER GRIPPER
REFERENCE:	Olympus Quote No. 10472, Items 5, 6, and 11
DATE:	January 27, 2016

This letter is provided to verify that the referenced quotation and line items are being purchased to use with a team of four students at Idaho State University in Pocatello, Idaho. The purpose is to perform studies relative to the potential for implementation of this type of robot for use in a nuclear post-irradiation examination facility as a programmed material handling unit.

The purchase of this combination will be performed through Battelle Energy Alliance (BEA), prime contractor at the Idaho National Laboratory, for which these student are currently serving as Intern employees. BEA is formally aligned, by university partnerships, with this and a number of other universities.

Should any questions arise, please contact the students mentor, Kevin M. Croft at 208-526-8276.

Idaho State UNIVERSITY

Sage Thibodeau <thibsage@isu.edu>

Machine Vision integration to UR5

13 messages

Sage Thibodeau <thibsage@isu.edu> Fri, Apr 1, 2016 at 1:22 PM
To: ayust@olympus-controls.com
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Alex,

Hi, my name is Sage Thibodeau and I am part of the senior design team that is designing the robotic system that uses Cognex machine vision integrated with a Universal Robot UR5 for the Idaho National Laboratory. I have been experimenting with and learning how to use the UR5 and the Cognex In-sight 1100 that we have purchased and I have a few questions.

The process that is being run is that a cylindrical container comes into the room through a transfer system. The location that the container enters the room is fixed, so the robot can easily grab it and then place it in a holder so that it may be opened. However, in order to open the container, the correct side of the container needs to be facing out towards the robot to open the lid. This is where the machine vision comes into play. I have already used the PatMax tool to train an image of the container and it is able to determine the orientation of the container quite well.

My question is how do I communicate the angle the container needs to rotate to the UR5 so that it can pick up the container, rotate it, and then put it back into the holder so that it can be opened?

So far what I have done is gone to spreadsheet, set up a TCPDevice (Functions->Input/Output->Network) using its default settings, and then used WriteDevice to send the angle to the robot. Am I on the right track with that?

As for the UR5 receiving the Cognex information, I have set up the Cognex as a MODBUS client using the Cognex IP address. I have also set up register inputs for the information that I need so that I can use them as variables in the program. Is this the correct way to connect the two devices and what else might need to be done?

It is also my understanding that the orientation that the container needs to rotate must be converted into the UR5 coordinate system [x,y,z,Rx,Ry,Rz]. How might I make it so that the UR5 only rotates the the wrist connected to the gripper without moving any of the other joints? My attempts at putting this in a program causes the whole robot want to rotate all the way around.

I know that there is a lot to go through here, so let me know if you need any clarification. If it's alright with you, I wouldn't mind seeing a sample program for the Cognex vision system as well as any Universal Robot code or pictures of PolyScope you might have so that I have something to go off of.

My team and I greatly appreciate you taking the time to assist us!

Best Regards,

Sage Thibodeau
M.E. Undergrad, Idaho State University
Intern, INL
Cell: (907)-723-3855
Email: thibsage@isu.edu

Croft, Kevin M <kevin.croft@inl.gov> Fri, Apr 1, 2016 at 1:39 PM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: Alex Yust <ayust@olympus-controls.com>

Thanks to all for your help on this. Please let me know if I can assist.

Sincerely,
Kevin Croft
[Quoted text hidden]
--
Kevin M. Croft
Sr. Advisory Engineer, INL
(208) 526-8276 (Office)
(208) 705-8113 (Mobile)

Alex Yust <ayust@olympus-controls.com> Fri, Apr 1, 2016 at 4:46 PM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Hi Sage,

I can indeed help you get this running. Are we talking about an end-effector mounted camera or a fixed mount camera?

In general, we will not be using MODBUS. I generally just use TCP/IP for communication between the UR and the camera.

I've got lots of example code that I'd be happy t5o share as soon as I know a bit more about your set-up.

Looking forward to hearing back.

Thanks!

From: Croft, Kevin M [mailto:kevin.croft@inl.gov]
Sent: Friday, April 01, 2016 12:40 PM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: Alex Yust <ayust@olympus-controls.com>
Subject: Re: Machine Vision integration to UR5

[Quoted text hidden]

Sage Thibodeau <thibsage@isu.edu> Sat, Apr 2, 2016 at 11:00 AM

To: Alex Yust <ayust@olympus-controls.com>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Alex,

Thanks for getting back to me! The camera is an end-effector mounted camera. The plan is to move the robot directly above the container holder so that the camera has a good top view of the container and can see how much it needs to be rotated for the correct side to be facing out towards the robot.

Let me know if you need anymore info!

Thanks,
Sage
[Quoted text hidden]

Alex Yust <ayust@olympus-controls.com> Mon, Apr 4, 2016 at 9:51 AM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Sage,

Have you calibrated the camera and are you getting accurate angle values already?

If so, as far as communication goes, the "TCPDevice" function of the camera should be set up as a Server communicating on port 30000, packet type "String CR+LF" and protocol "TCP/IP." After the angle has been identified by the PatMax tool, you will need to use the "FormatString" function with the following settings:

- Leading text: (
- Trailing text:)
- Terminators: CR+LF
- Use Delimiter "checked": Standard, "Comma"
- Pull in the angle data to the function from the PatMax tool as a "floating point" number with the required number of decimal places

Finally, to get the data sent to the UR correctly after the camera is triggered, use a "WriteDevice" function pointing at the "TCPDecive," the "FormatString" function output and an "Acquisition Job Complete" event

Next, you need to set up the UR to receive the data. Use the following format for opening a port and receiving data:

socket_start:= False

```
Set micro_TRIG=On
Loop socket_start≟ False
 socket_start≔socket_open("192.168.10.46",30000)
Loop ReadWaypoint[0]≠1
 ReadWaypoint≔socket_read_ascii_float(1)
socket_close()
Set micro_TRIG=Off
```

Note in the above code that the “socket_open” command is pointing at the IP address of the camera. Also, the above code does not contain any error handling in case the robot doesn’t receive the data it expects from the camera. Feel free to experiment and add error handling as you see fit.

From this point, there are multiple ways to proceed. Perhaps the one that is most intuitive is the following:

- Move to a location directly above part
- Trigger the camera
- Loop (WHILE) until angle data from the camera is received in radians
- Create a pose variable in the form: RotatePose = p[0,0,0,0,0, ReadWaypoint[1]]
- Command the robot to move to “RotatePose” using a moveL relative to the “Tool” feature

That should be it. If you have any other questions, let me know. I can also give you some example code if need be but most of what I have also has x and y moves in it so it is a bit more complex.

Hope this helps.

Thanks!

From: Sage Thibodeau [mailto:thibsage@isu.edu]
Sent: Saturday, April 02, 2016 10:00 AM
To: Alex Yust <ayust@olympus-controls.com>

Cc: Croft, Kevin M <kevin.croft@inl.gov>

[Quoted text hidden]

[Quoted text hidden]

Sage Thibodeau <thibsage@isu.edu> Mon, Apr 4, 2016 at 12:40 PM
To: Alex Yust <ayust@olympus-controls.com>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Alright, thank you Alex! I'll give this a try and get back to you if I have any more questions. I greatly appreciate your help!

Thanks,

Sage
[Quoted text hidden]

Sage Thibodeau <thibsage@isu.edu> Tue, Apr 5, 2016 at 10:09 AM
To: Alex Yust <ayust@olympus-controls.com>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Alex,

Ok after giving it a go, I have a couple more questions.

I was able to get the Cognex spreadsheet set up for communications well enough, but I had a little trouble programming the UR5. My first problem starts at:

Set micro_TRIG=On

When I use Polyscope's "Set" function, I am faced with a few options setting either analog or digital inputs to a given value. I do not see an option that would set micro_TRIG=On. If I try writing this command in script, then the program doesn't recognize the function "Set" or the value "On". What am I missing?

Also, how is the UR5 triggering the camera in its program? I assume that the purpose of the "Set micro_TRIG=On" is to trigger the camera, but I'm just curious what sort of signal is being sent to the Cognex In-sight? And how should I have the trigger set on the spreadsheet (Camera, Continuous, Network...)? To trigger the camera on the computer, I usually put the trigger on continuous and then turn the camera online, but in this application the camera won't be connected to the computer.

Thanks,
Sage

[Quoted text hidden]

Alex Yust <ayust@olympus-controls.com> Tue, Apr 5, 2016 at 10:21 AM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Sage,

The “Set micro_TRIG=On” command is turning a digital output “ON”. The reason it’s called “micro_TRIG” and not “DO0” is because I gave the output that name inside of the UR controller so I would have a better idea of what I was doing while developing the code. That output from the controller is wired directly into the dedicated trigger input on the camera. This is how I would suggest you trigger the camera as well.

To answer your second question, I believe “Camera” mode for the camera should look to the dedicated input for its trigger. Take a look at the help page for the image acquisition cell within In-Sight explorer for additional explanation. Also, in general, you should leave the camera always “online” while running your application and trigger it as needed using one of the other triggering options. Taking the camera “offline” in generally used for making code changes, not as a method of triggering.

Let me know if you have any other questions.

Thanks!

From: Sage Thibodeau [mailto:thibsage@isu.edu]
Sent: Tuesday, April 05, 2016 9:09 AM

[Quoted text hidden]

[Quoted text hidden]

Sage Thibodeau <thibsage@isu.edu> Thu, Apr 7, 2016 at 11:21 PM
To: Alex Yust <ayust@olympus-controls.com>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>
Bcc: Larinda Nichols <nichlari@isu.edu>

Alex,

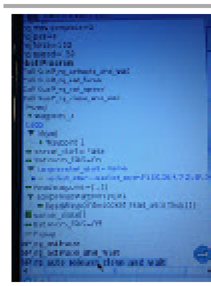
Alright thanks! I got the trigger all set up and running now! However, I'm still having a problem with the socket_open. I set it up so that the code looks like this:

```
socket_start:=False
micro_TRIG=On
Loop socket_start≟False
     socket_start:=socket_open("169.254.7.218",30000)
ReadWaypoint:=[1,1]
Loop ReadWaypoint[0]≠1
   ReadWaypoint:=socket_read_ascii_float(1)
socket_close()
Set micro_TRIG=Off
```

So that the loop keeps running until socket_start:=True, but for some reason the socket won't open so it gets stuck in an infinite loop. I have the correct IP address of the camera and designated port number entered into the socket_open. On the Cognex spreadsheet, I have the TCPDevice set up as the server (Host Name is blank), Port: 30000, Protocol: TCP/IP, and Packet Type: String CR+LF. I have the format string set up the way you said with the angle I need in it. The WriteDevice function is set up as WriteDevice(Image,TCPDevice,FormatString). And the camera is online of course. I just can't seem to locate where my error is at.

I attached a screen shot of the UR code that I have just in case there is something on there I may have screwed up. I'm hoping you might have some ideas as to why the socket won't open or why there isn't a successful connection. I appreciate your help on this!

Thanks,
Sage
[Quoted text hidden]



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1161K

Alex Yust <ayust@olympus-controls.com> Fri, Apr 8, 2016 at 9:04 AM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Sage,

What is the IP address of the robot?

Thanks

From: Sage Thibodeau [mailto:thibsage@isu.edu]
Sent: Thursday, April 07, 2016 10:21 PM

[Quoted text hidden]

[Quoted text hidden]

Sage Thibodeau <thibsage@isu.edu> Fri, Apr 8, 2016 at 11:31 AM

To: Alex Yust <ayust@olympus-controls.com>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Alex,

The IP address of the robot is just 0.0.0.0

Thanks
[Quoted text hidden]

Alex Yust <ayust@olympus-controls.com> Fri, Apr 8, 2016 at 12:47 PM
To: Sage Thibodeau <thibsage@isu.edu>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Sage,

That is your problem. You should have the robot on the same subnet as the camera (example - Camera: 169.254.7.218 Robot: 169.254.7.200)

From: Sage Thibodeau [mailto:thibsage@isu.edu]
Sent: Friday, April 08, 2016 10:31 AM

[Quoted text hidden]

[Quoted text hidden]

Sage Thibodeau <thibsage@isu.edu> Fri, Apr 8, 2016 at 2:01 PM
To: Alex Yust <ayust@olympus-controls.com>
Cc: "Croft, Kevin M" <kevin.croft@inl.gov>

Alex,

Alright, I finally got the UR5 to read the machine vision coordinates! Thank you so much! You've been a big help!

[Quoted text hidden]

Idaho State UNIVERSITY

Larinda Nichols <nichlari@isu.edu>

Larinda Nichols - Enclosure Concepts

1 message

Larinda Nichols <nichlari@isu.edu> Fri, Feb 26, 2016 at 9:22 PM

To: dean.blanton@inl.gov

Hi Dean!

I have put together a short PowerPoint and attached it to this email. I figured this would be the easiest way to explain the three concepts we are looking at for a robot enclosure. Please know that we are completely open to suggestion since you guys would know better than anyone if we are way off base. I actually came up with the Concept #1 after our conversation about "keeping it simple". See...I can be taught!

Anyway, I appreciate your time. Don't feel rushed to get back to me, just when you have a m. And definitely call me if you have any questions! I'm sure I didn't explain a few things as good as I could have.

Thank you so very much for all your help!

--

Larinda Nichols
Senior Undergraduate Student
Nuclear & Mechanical Engineering
Idaho State University

Enclosure_Concepts_LN.pptx
1442K

Idaho State University

Larinda Nichols <nichlari@isu.edu>

Larinda Nichols - Enclosure Concepts

Miller, Brandon D <brandon.miller@inl.gov> Tue, Mar 1, 2016 at 8:12 AM
To: Larinda Nichols <nichlari@isu.edu>

Nice presentation. Few things i noticed that someone or I would ask.

Concept 1: What happens if I drop the small enclosure. Can I retrieve it? If it drops in the FIB tray yes. What about a drop and a retrieve? Did i contaminate the small enclosure and how do i get that enclosure to a shielded contaminated area to unload the enclosure and clean the sample?

Concept 2: Alot of the same questions from concept 1. Enclosures have two purposes. Confinement for drops and contamination. By having an opening on the enclosures, we dont have a sealed system. We either have to have a sealed enclosure or have an inward flow. This might mean having a hepa vacuum sucking on the enclosure to provide a face velocity that will prevent release.

Concept 3: Same issue with concept 2.

Hope this helps. Let me know if you have any questions. Looks good otherwise. B
[Quoted text hidden]

APPENDIX HH: Fall Presentation to INL

1

ISU Project Location (Pocatello, Idaho)

Measurement & Control Engineering Research Center
(MCERC)

Senior Design Project

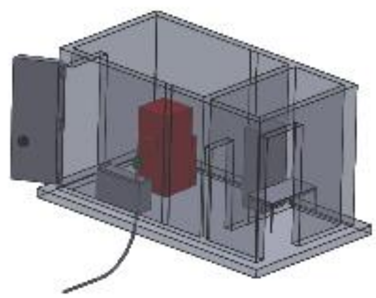
- **PROBLEM STATEMENT:**

  INL needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.

- **OBJECTIVE:**

  Investigate the integration of kinematics, electronics, material sciences and radiation physics for the design of a system for use in a nuclear hot cell environment.

Conceptual Design – Instrumentation Cell



Constraints & Specifications

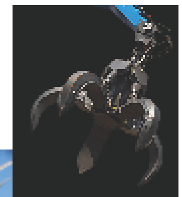
- **ACCURACY**
  - System must place sample within a 0.5 in. radius from the desired location
- **REPEATABILITY**
  - System must meet the accuracy specification 99% of the time
- **RADIOLOGICAL ENVIRONMENT**
  - Equipment must be able to withstand up to $1x10^8$ Rad exposure
- **RADIOLOGICAL SAFETY**
  - Personnel shall not be physically present in the cell during operation
- **OVERALL COST OF PROJECT**
  - Must meet a budget of $50,000
- **COMPLEXITY**
  - Project to be completed within 9 months (May 2016)

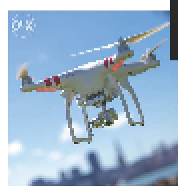
3

Idaho National Laboratory

Preliminary Ideas

1. MASTER SLAVE MANIPULATOR
2. ARMOR SUIT
3. ROBOTIC ARM
4. ROBOTIC ROVER
5. CHUTE/CONVEYOR BELT
6. CRANE CLAW
7. HELI-QUAD COPTER



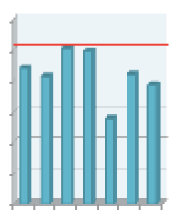


Idaho National Laboratory

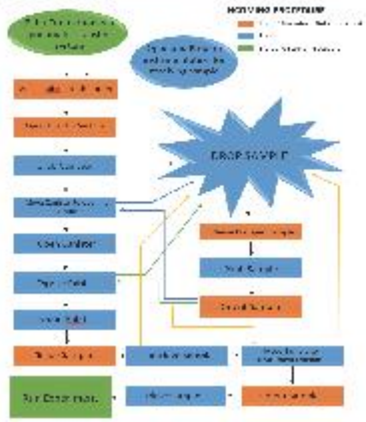
Decision Matrix

Specification	Weight	Concept 1	2	3	4	5	6	7
Removal/return of sample from pneumatic transfer system.	5	5	5	5	5	0	5	3
Removal/return to rabbit	5	4	5	5	5	0	3	3
Removal/return to instruments	5	4	5	5	5	0	1	1
Vision (Optics/window)	3	2	5	3	3	3	3	3
Ability to react to dropped sample	5	5	5	3	5	0	5	5
Accuracy	5	5	5	5	1	3	5	3
Repeatability	5	3	5	5	1	0	1	0
Multi-personnel operation (Lefty/Righty)	4	2	5	5	5	5	5	5
A total dose of 1 x 10^6 Rad shall be the basis for equipment radiological design (2 Ci Co 60)	5	5	0	5	5	5	5	5
No sharp edges	3	5	5	5	5	5	4	5
Safety	3	3	1	5	5	4	2	2
10-year life cycle	3	5	0	5	5	5	5	1
Easy to Upgrade/Modular	3	0	2	5	5	0	0	5
Cell Size (10.5' X 8')	4	3	5	4	5	3	5	5
Lifetime Cost	2	1	4	2	2	5	3	5
Complexity	2	5	0	2	2	5	4	0
	Total	217	212	258	247	143	216	198

Master Slave Manipulator	1
Armour Suit	2
Robotic Arm	3
UGV	4
Chute/Conveyor Belt	5
Crane/ Claw	6
Heli-Quad Copter	7



Process Flowchart



Current Work

Mock-up of Instrumentation Cell at MCERC

Idaho National Laboratory

Current Work

- Considerations for final choice of robotic system
  - Reach
  - Payload
  - Flexibility / Degrees of freedom
  - Cost
- Universal Robots
  - Easily programmable
  - Fast initial setup
  - Flexible deployment
  - Collaborative and safe

Idaho National Laboratory

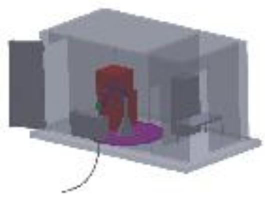
Current Work

(a) UR-3 (b) UR-5 (c) UR-10

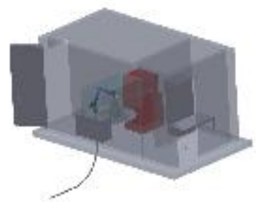
6

Current Work

DROPPED SAMPLE CONCEPTS



(a) Tray System



(b) Enclosure

Plan Going Forward

- Solidify decision and procure necessary components
  - Robot size
  - Vision system
  - Electronic sensors
  - Additional materials required
  - Complete analysis of system
- Determine retrieval and replacement of sample to/from RABBIT
- Determine a solution to the off-normal situation
  - If a sample is dropped, how does the robot retrieve it?

8

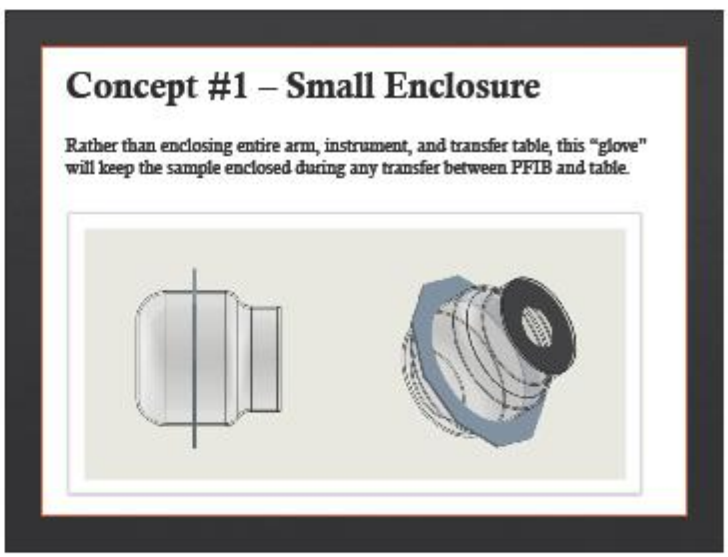
Deliverables

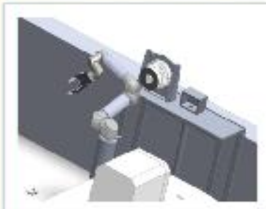
1. Proposal for Instrument Cell Layout
2. Recommendations for Final System
   - Robot
   - Vision System
   - Gripper
   - Additional System Components
3. Drop Sample Solution
4. Final Presentation at ISU (April 18-20th)
5. Final Presentation to INL
6. Final Report

Thank you for this opportunity!

Questions?

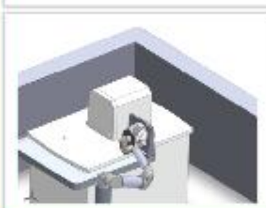
APPENDIX II: Enclosure Presentation to INL





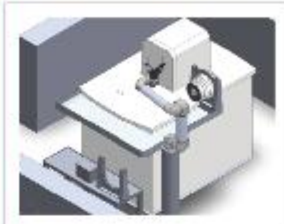
1. Robot removes sample from rabbit and orients sample in the gripper.

2. Robot slips into small enclosure that is anchored to the transfer table using a custom stand.



3. Robot slides enclosure up and out of the stand. Sample will remain completely enclosed until it reaches the PFIB table where another stand is placed to dock the enclosure.

*Even in the unlikely event that a sample falls out of (or is dropped by) the gripper, it will remain within the small enclosure, and the robot will return to the transfer table. Then, the robot could be manually operated to simply withdraw from the enclosure, turn it upside down, and free the sample back onto the table for reloading.

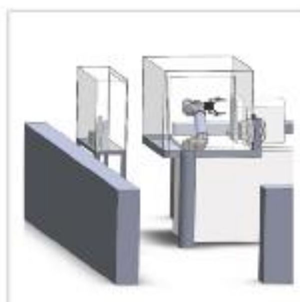


4. Robot withdraws from the enclosure freeing it to place the sample into the instrument.

- Potential to eliminate larger enclosure that might get in the way of robot movement and/or instrument maintenance.
- Small tray could be placed around the PFIB table (and the transfer table) if desired as an additional precaution in case the sample is dropped on either table and rolls – like a lip.

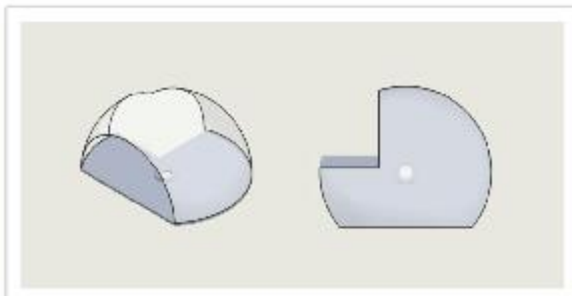
Concept #2 – Medium Enclosure

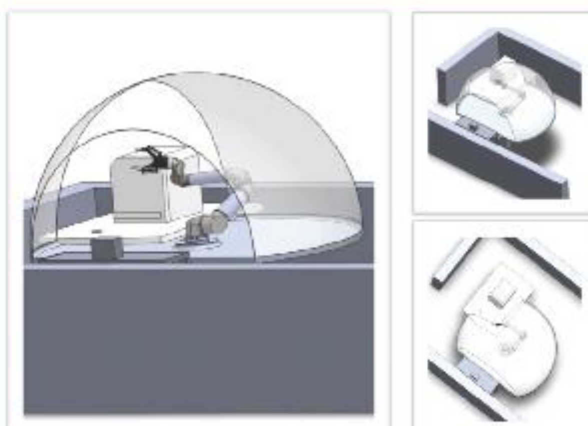
This is more or less Concept #1 with the addition of acrylic surrounds for both PFIB and transfer table if more enclosure is necessary.



Concept #3 – Large Enclosure

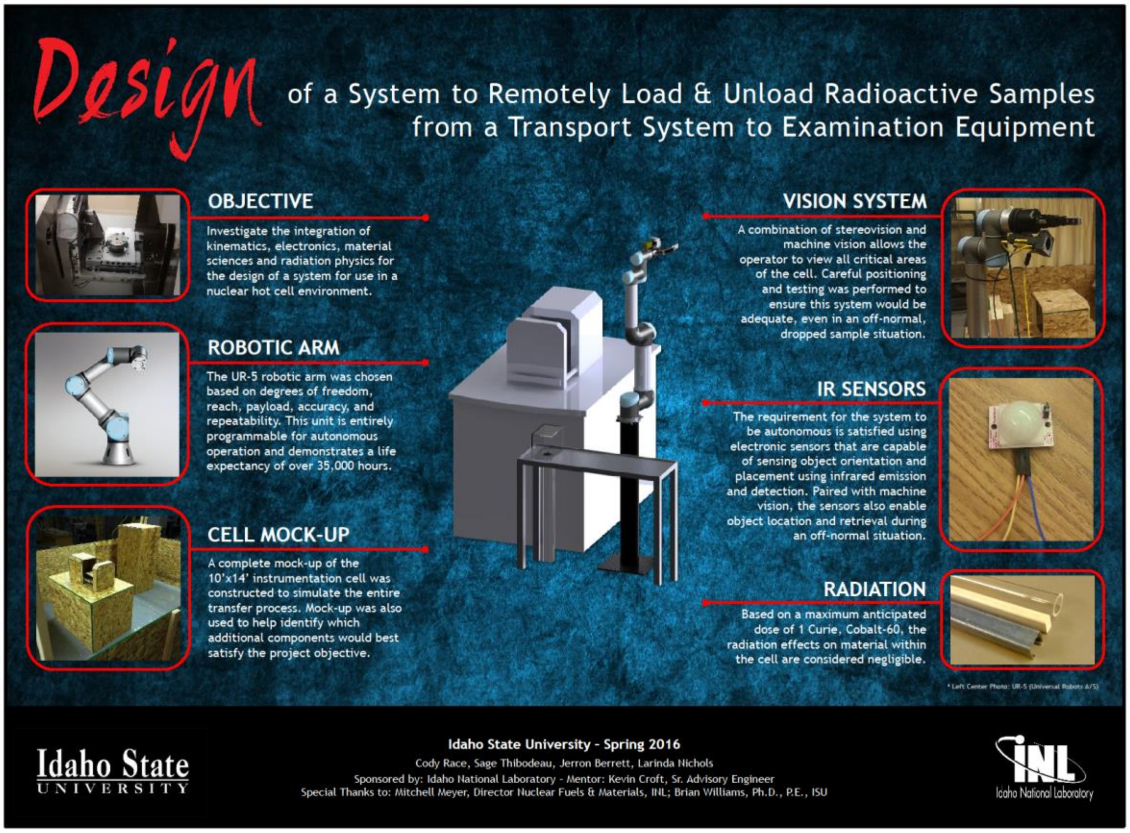
Dome enclosure (acrylic) mounted on aluminum tray. Extends the entire reach of the robot. Can be designed for easy disassembly for PFIB maintenance.






A FEW COMMENTS
These descriptions are extremely simplified, but hopefully they make sense.
Please give me a call if you have questions, or if you would like me to run through them with you.
208-705-5014 or nichlari@isu.edu
Any input or suggestions are most appreciated
Completely open to the idea of altering or combining ideas
THANK YOU!

APPENDIX JJ: Project Poster



APPENDIX KK: Team Meeting Minutes

MEMORANDUM

TO:	PROF HOFLE, PROF EBRAHIMPOUR
FROM:	SPLT
SUBJECT:	MEETING MINUTES – 20150826_SPLT_MINUTES
DATE:	AUGUST 26, 2015
CC:	KEVIN CROFT

Attendees: Larinda Nichols, Jerron Berrett, Cody Race, Sage Thibodeau

Absent: None.

Call to order: 8:00am

- Larinda presented a brief overview of existing project information and reminded team of meeting scheduled with INL for September 9th at 2:30pm, MFC.
- Cody recommended a mentor meeting be held prior to September 9th.
  - Action: Larinda will set up meeting for Monday, August 31st, 8:30-10:00am at ISU Library to include all team members and Kevin Croft (mentor). Due: 8/26/2015.
- Kevin Croft responded and requested that the team draft the Project Proposal.
  - Action: Cody will draft Project Proposal from pre-existing Project Scope, collective team input, and today's minutes. Due: 8/31/2015.
- Team held an open discussion concerning possible project roles.
- Jerron agreed that he would be well suited for the kinematics portion of the project.
- Sage discussed his previous experience with mechatronics and accepted responsibility for the project's electrical components.
- Cody and Larinda chose a number between one and ten, per Jerron's suggestion, to decide between visual components and hardware.
- Larinda wisely chose five and will now be focusing on hardware.
- Cody indicated he had previous experience in photography and visual components; therefore, all team members were satisfied.
  - Action: Team will present tentative project roles to mentor for approval. Team will follow up with Senior Design Instructors for additional approval following meeting with mentor. Due: 8/31/2015.
- Cody mentioned the usefulness of a whiteboard for brainstorming. The team agreed that a private project and meeting location should be pursued.
  - Action: Team will follow up with Dr. Williams, as he mentioned previously that he had available space. Due: 8/26/2015.

Adjourn: 9:05am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 8212015_SPLT_MEETING
DATE: AUGUST 31, 2015
CC: KEVIN CROFT

Attendees: Cody Race, Larinda Nichols, Sage Thibodeau, Jerron Berret, and Kevin Croft

Absent: None

Call to order: 8:38am

- Students Cody Race, Larinda Nichols, Sage Thibodeau, and Jerryn Berret gather in Eli Oboler Library to meet project mentor Kevin Croft
- The team went around in circle introducing themselves starting with Larinda, Jerryn, Cody, and then Sage
- Kevin Croft introduced himself and then presented a PowerPoint on his career and experience
  - Attended University of Idaho and obtained bachelor in Mechanical Engineering
  - Extensive experience in tele-operated robots
  - Pointed out other skills relevant to the project
- Kevin asked the group what their plan was for tackling the project
  - Larinda offered Kevin the group's project scope and mentor
  - Action: Kevin was assigned to look over the scope and offer feedback to Cody
- Kevin presented the Universal Robot 10 as a possible system to be used for the project
  - Action: Sage, Cody, Larinda, and Jerron assigned to look into the UR 10 robot and give feedback on their thoughts
- Group bids farewell

Adjourn: 9:55am

MEMORANDUM

TO:	PROF HOFLE, PROF EBRAHIMPOUR
FROM:	SPLT
SUBJECT:	MEETING MINUTES – 20150909_SPLT_MINUTES
DATE:	SEPTEMBER 9, 2015
CC:	KEVIN CROFT

Attendees: Larinda Nichols, Cody Race, Jerron Berrett, Sage Thibdeua, Kevin Croft, Mitch Meyer

Absent: None.

Call to order: 2:30pm

- Students Jerron Berrett, Cody Race, Larinda Nichols, and Sage Thibdeua drove to MFC (Materials Fuels Complex).
- The team was escorted to a conference room in which a meeting was being held.
- The team introduced themselves to everyone in the conference room
- Larinda then talked about our senior project to the group of people in the conference room
  - Load and unload radioactive samples from a transport system to examination equipment
  - Others gave feed back on what they thought of the project
- Next Mitch gave the team and Kevin a tour of some buildings at MFC
  - Started with EML (Electronic Microscopy Laboratory)
  - Then IMCL (Irradiated Materials Characterization Laboratory)
  - Last was HFEF (Hot Fuel Examination Facility)

Adjourn: 5:00pm

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: SPLT
SUBJECT: MEETING MINUTES – 20150914_SPLT_MINUTES
DATE: SEPTEMBER 14, 2015
CC: KEVIN CROFT

Attendees: Larinda Nichols, Jerron Berrett, Cody Race, Sage Thibodeau

Absent: None.

Call to order: 8:00am

Review of actions from last formal team meeting on 8/26/2015. Previous two meetings consisted of mentor/team introductions (8/31) and INL tour (9/9).

- Cody was assigned to draft Project Proposal for team review by 8/31/2015.
  - Project Proposal completed, reviewed, and uploaded to Moodle on 9/4/2015.

- Team was to follow up with Dr. Williams concerning MCERC building space.
  - Access was granted to MCERC building. Meeting to be held there going forward.

Remainder of meeting was spent brainstorming ideas on how to generally transport something from one place to another.

- Chalkboard list of ideas created by collaborative team input.
- List saved to a preliminary Microsoft Excel spreadsheet on team drive.
- Pros and Cons were given to Cody by all members to input under each idea in the sheet.

Actions due by next Monday, September 21st:

- New meeting location needs to be sent to Kevin Croft. Larinda will set up a reoccurring calendar invitation as well as remind Kevin that mentor agreement is due 9/16.
- The team still does not have access to Dr. Williams' lab. Cody will follow up with him.
- Minutes from 8/31 were assigned to Sage.
- Minutes from 9/9 were assigned to Jerron.
- Team agreed samples of RABBIT and met-mounts would be helpful. Larinda will contact Paul Lind to see about the possibility of obtaining a few.

Adjourn: 9:45am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: SPLT
SUBJECT: MEETING MINUTES – 20150921_SPLT_MINUTES
DATE: SEPTEMBER 21, 2015
CC: KEVIN CROFT

Attendees: Larinda Nichols, Jerron Berrett, Sage Thibodeau, Kevin Croft

Absent: Cody Race (excused)

Call to order: 8:30am

- Kevin Croft began meeting with a safety share about the importance of being safe at home as well as at the workplace. Kevin explained that the INL begins every meeting with a safety share, and that he would like us to prepare a safety share and meeting agenda for next time.
    - Action: Sage was asked to prepare a safety share and meeting agenda for next meeting. Due 10/5/2015.

- Kevin asked team to pick a team leader to represent the project. Team voted Cody would be best suited for the task.
    - Action: Team to ask Cody if he will be team leader and notify Kevin. Due 10/5/2015.

- Kevin discussed his perception of the project and asked how he could be of help in our design process. Larinda asked Kevin if he could provide a list of requirements for the team to use as a baseline for ranking the list of ideas the team created during their 9/14 meeting. Kevin agreed to provide the team with these requirements by the end of the day.

- Kevin provided the team with a few suggestions in going forward. He said there was a device called a "ball and tong" that might be a possible solution. He also mentioned that the company he was working with for the commercial RABBIT capsules for the pneumatic system was Kelly Pneumatics, and that we might be able to obtain some information from them in our research.

Adjourn: 9:45am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: SPLT
SUBJECT: MEETING MINUTES – 20150930_SPLT_MINUTES
DATE: SEPTEMBER 30, 2015
CC: KEVIN CROFT

Attendees: Larinda Nichols, Jerron Berrett, Sage Thibodeau, Cody Race

Absent: None

Call to order: 9:00am

- Team continued to discuss and rate concepts using the decision matrix.
  - Cody brought in his personal laptop with updated matrix.
  - Matrix was projected onto the whiteboard.
  - Ratings were collectively agreed upon and weighted.

- Preliminary results of discussion*:

  1) Robotic Arm
  2) Robotic Rover
  3) Crane/Claw

  * COST WILL STILL NEED TO BE CONSIDERED BEFORE A FINAL DECISION

- Cost of each concept needs to be discussed with Kevin and matrix updated.
  - Action: Team will ask Kevin about cost associated with each idea. Due 10/5.

- Team looked up Kelly Pneumatics (www.kellytubesystems.com) to research commercial RABBIT capsules (as per Kevin's request last meeting).

Adjourn: 9:45am

MEMORANDUM

TO:	PROF HOFLE, PROF EBRAHIMPOUR
FROM:	TEAM SPLT
SUBJECT:	MEETING MINUTES – 20151005_SPLT_MINUTES
DATE:	OCTOBER 5, 2015
CC:	KEVIN CROFT

Attendees: Jerron Berrett, Larinda Nichols, Cody Race, Sage Thibodeau, Kevin Croft

Absent: None.

Call to order: 8:30

- Safety Share: Sage
    - Engineering Lab floorplan and evacuation routes, fire extinguisher locate.
- Requirements
    - Went through with Kevin Croft to determine that our requirements for our concept matrix matched his expectations
    - Was pleased with the requirements, wanted a little bit of more definition on some of the requirements.
        - Action: Cody send Kevin the matrix to look more in depth with
        - Action: Look up ROS (Underwater Vision System)
    - Kevin gave some background costs for the concepts that he has dealt with
        - Action: Team needs to determine the costs of the other concepts
- Project Planning
    - Action: Next meeting, team needs to determine the project planning and create an up to date Gantt Chart with major deadlines for ISU and INL.
- SPL Status
    - Current design came in over budget so finding new ways to cut the cost.
    - Creates more demand for the robotics systems
    - Action Item: Kevin to send us information about stipend
- Direction of Work
    - Finish Concept Matrix
    - Update Gantt Chart

Adjourn: 9:50

MEMORANDUM

TO:	PROF HOFLE, PROF EBRAHIMPOUR
FROM:	SPLT
SUBJECT:	MEETING MINUTES – 20151007_SPLT_MINUTES
DATE:	OCTOBER 7, 2015
CC:	KEVIN CROFT

Attendees: Larinda Nichols, Cody Race, Jerron Berrett, Sage Thibodeau

Absent: None.

Call to order: 8:00am

- Team updated Gantt chart
- Agreed to have our 3 choices for our project by the end of meeting today
- Talked about cost for our options to narrow down the options
- Agreed on top three resultant options
- This was decided using decision matrix with robotic arm the highest, then robotic rover, last master salves.

Actions

- Larinda is going to Contact Kate to set up an end of semester presentation with Mitch
    - Due date: Undecided
- Assign team members to put together slides for the presentation
    - Due date: Sunday, October 11, 2015

Adjourn: 9:45

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 10142015_SPLT_MEETING
DATE: OCTOBER 14, 2015
CC: KEVIN CROFT

Attendees: Cody Race, Larinda Nichols, Sage Thibodeau, Jerron Berret

Absent: None

Call to order: 8:00am

- Group addressed critiques from previous project update on 10/12
  - Reviewed list of requirements
  - Turned requirements and constraints into quantifiable specs
- Action: Cody sent quantifiable specs to Prof. Mary for review
- Group talked about upcoming report segment due
  - Assignment: Each group member tasked with writing a brief paragraph on qualifications and what they will bring to this group.
- Assignment: Larinda tasked with creating a house of quality for final design choice
- Assignment: Cody and Sage tasked with talking to Brian Williams about access to lab
- Team bids farewell

Adjourn: 9:45am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 10192015_SPLT_MEETING
DATE: OCTOBER 19, 2015
CC: KEVIN CROFT

Attendees: Cody Race, Larinda Nichols, Sage Thibodeau, Jerron Berret, and Kevin Croft

Absent: None

Call to order: 8:10am

- Phone conference with Kevin
  - Kevin questioned group about internship with INL
  - Group Confirmed they were coming up to IF on Friday 10/23
- Group went over report criteria for the first report segment
- Action: Sage emailed his qualification and task segment for review by his teammates
  - Group looked at the format of qualifications on the line and decided qualifications needed to be revised
- Team broke down processes that system would need to carry out step by step
  - Set ground work for components necessary to carry out task; morphology chart
- Action: Cody sends email to Kevin asking who is in charge of the design of the pneumatic transfer system
- Team constructed introduction, problem statement, objective, and specs for report segment

- Team bids farewell

Adjourn: 9:44am

MEMORANDUM

TO:	PROF HOFLE, PROF EBRAHIMPOUR
FROM:	TEAM SPLT
SUBJECT:	MEETING MINUTES – 11022015_SPLT_MEETING
DATE:	NOVEMBER 2, 2015
CC:	KEVIN CROFT

Attendees: Cody Race, Larinda Nichols, Sage Thibodeau, Jerron Berrett

Absent: None

Call to order: 8:00am

- Group turned process into flow chart
- From flow chart, group made preliminary morphology chart based on tasks the system needs to carry out
  - Addressed sensors, grabber, canister and rabbit design, ways to take out sample, and ways to place sample
  - Dropped sample troubleshoot methods
- Action: email must be sent to Kevin by 11/6 regarding floor plan for the hot cell, size of instruments, internship status, rabbit, and the pneumatic transfer system used
- Discussion: what type of robotic arm options might be feasible
- Action: Contact INL about setting up a meeting to discuss budget and possible solutions to the system
- Action: Tasks given to individual group members due 11/4
  - Sage – Sensors for dropped sample and sensing sample in room
  - Jerron – Find possible degrees of freedom and size of robot necessary
  - Larinda – Plexi-glass radiation resistance
  - Cody – Underwater camera system research and other possible camera systems
- Action: Larinda update meeting schedule with Kevin
- Group decided presentation topics addressed

MEMORANDUM

TO:	PROF HOFLE, PROF EBRAHIMPOUR
FROM:	SPLT
SUBJECT:	MEETING MINUTES – 20151207_SPLT_MINUTES
DATE:	DECEMBER 7, 2015
CC:	KEVIN CROFT

Attendees: Larinda Nichols, Jerron Berrett, Sage Thibodeau, Cody Race, Kevin Croft

Absent: None

Call to order: 8:00am

- Prior to mentor meeting, team discussed their spring schedules.
- Team collaborated on a new Google calendar to be accessible to the entire team.
- Action: Cody has asked the team to get onto the calendar sometime this week and mark any days over Christmas Break that they will be unavailable. (Team: Due Monday, December 14th)

Mentor meeting with Kevin Croft (8:30am)

- Showed Kevin the mock-up of instrumentation cell in progress. Talked about what was left (instruments and placement of equipment.
- Discussed results of calibrating stereo-vision. BNC cables to compare with a regular camera are still enroute. Kevin will let the team know when they arrive at INL.
- Talked about what other materials we need over Christmas Break and Kevin mentioned that there was room in the budget if we wanted to look at McMaster Carr for materials.
- Action: Team needs to decide ASAP what kind of robot would work best for this application. Current choice is between UR-5 vs. UR-10. (Team: Due January 11th, 2016)
- Action: Larinda will ask Dean Blanton if there is a scale at EML to measure the force required to open the instrument tray. If not, team may need to bring a measuring device with them to the tour next week if possible. Perhaps a fishing scale. (Larinda: Due Wednesday, December 16th)
- Action: Team has agreed to send the INL presentation to Kevin by Monday morning for review. (Team: Due Monday, December 14th)
- Team agreed to meet Friday morning at 8:00am to work on the INL presentation.

Adjourn: 9:45am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 0112116_SPLT_MEETING
DATE: JANUARY 12, 2016
CC: KEVIN CROFT

Attendees: Cody Race, Larinda Nichols, Sage Thibodeau, Jerron Berrett, and Kevin Croft

Absent: None

Call to order: 8:00am

- Group assembled to discuss current status of project and to continue construction of the 3D sample cell mockup.
- Kevin suggested that the mockup be reconstructed out of plywood rather than the current cardboard being used.
    - Action: Research cost of constructing plywood mockups
- Group discussed specs and requirements needed to finalize a decision on a size of the robot arm.
    - Total reach, walking paths in the cell, radius of dropped sample containment
- Action: Group to write up a recommendation report for the size of the robot giving all research done and reasons for choice by 01/18/16.
- Medical Note: Larinda announced to the group that she has Thyroid Cancer that will need treatment and may be unavailable to perform her duties until she has recovered from the treatments.
    - Group gave their greatest sympathies and expressed that it would be no problem for her to take a rest.
- Kevin left meeting at 9:58am
- Group continued construction of mockup
- Group bid farewell

Meeting Adjourned at 10:40 am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 20160120_SPLT_MINUTES
DATE: JANUARY 20, 2016
CC: KEVIN CROFT

Attendees: Jerron Berrett, Cody Race, Sage Thibodeau, Kevin Croft, Brady Orchard, Brandon Miller, Dean Blanton, Mitchell Meyer, Kate Richardson

Absent: Collin Knight, Paul Lind, Ronald Johansen, Tom Pfeiffer, Larinda Nichols

Call to order: 1:00 pm

- Gave update presentation to INL staff
  - Introduced the team
  - Showed the lab and building of where the work is being performed
  - Discussed last semester's work
    - Decision Matrix
    - Preliminary Ideas
    - Process Flow Chart
  - Discussed current work
    - Robot size
    - UR-5
    - UR-10
    - Dropped sample
  - Discussed work still left to do
    - Vision system
    - Sensors
    - Deliverables
- Discussed our dropped sample concept regarding an enclose
  - Liked the idea for Rad safety
- Want to make the lab a demonstration
- Action Items:
  - Kevin Corft, Jerron Berrett, Cody Race and Sage Thibodeau to discuss the final robot size and have an order placed by Friday 1-29-2016
  - Cody Race, Jerron Berrett to upgrade mock layout of the room from cardboard to plywood to be more permanent for demonstrative purposes.

Adjourn: 2:10

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 20160126_SPLT_MINUTES
DATE: JANUARY 26, 2016
CC:

Attendees: Jerron Berrett, Cody Race, Sage Thibodeau, Larinda Nichols, Kevin Croft

Absent: None

Call to order: 8:17 am

- Kevin discussed the details of his business trip to Eugene, Oregon
  - NuScale has asked him to be a consultant for their remote handling project

- A discussion was held concerning the GANTT Chart
  - Reviewed last semester
  - Previewed this semester
  - Prioritized items awaiting action

  ACTION: Kevin will purchase the UR-5 and have it dropped shipped to team
  DUE: ASAP. Anticipated arrival in 4-5 weeks

  ACTION: Kevin will purchase remaining supplies for mockup from McMaster
  DUE: ASAP. Anticipated arrival by next week

- Team discussed possibilities for carrier
  - Flip top/clamp stage

- Team bids farewell to Kevin and proceeds to update task board

  ACTION: The stand for the robot needs to be designed and built before robot arrives. Team has agreed to travel to Shoshone to build the stand on the weekend of SuperBowl. Cody was tasked to submit the basic design to Kevin for approval.
  DUE: February 8, 2015

Adjourn: 10:30 am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 20160202_SPLT_MINUTES
DATE: FEBUARY, 02 2016
CC:

Attendees: Jerron Berrett, Cody Race, Larinda Nicholas, Sage Thibodeau, and Kevin Croft

Absent: None

Call to order: 8:00am

- Kevin let the team know that the robot has been ordered
  - Robot will be here with in the next week
  - Gripper for robot will be about 4 weeks out

- The team and Kevin discussed a carrier system
  - Holding the carrier in a clamp device
  - Recognition that carrier is open

  Action: Sage look into Machine vision and color sensing sensors

- Team talked about the stand for the robot
  - Make the stand adjustable

- Team discussed enclosures for the robot
  - One enclosure around the entire system
  - Two enclosures with one around the instrumentation and one around the table that the carrier comes in with
  - Two enclosure system would also have an enclosure around the griper as well

Adjourn: 10:30am

MEMORANDUM

TO: PROF HOFLE, PROF EBRAHIMPOUR
FROM: TEAM SPLT
SUBJECT: MEETING MINUTES – 0112116_SPLT_MEETING
DATE: FEBRUARY 16, 2016
CC: KEVIN CROFT

Attendees: Cody Race, Larinda Nichols, Sage Thibodeau, Jerron Berrett, and Kevin Croft

Absent: None

Call to order: 8:15am

- Kevin delivers the Universal Robot UR-5 to the MCERC lab where the mockup is being constructed.
  - Stand to be constructed the night of February 16 by SPLT team using materials previously obtained from Pacific Steel.
  - Once anchored into concrete, the robot will be mounted to the stand
- Kevin also delivers two additional computer monitors and two cameras that were used for the Yucca Mountain project as machine vision.
- Group discussed progress of mockup and goals for finishing mockup.
  - Clamp concepts, machine vision and sensors, and pneumatic transfer canisters/transport still remain to be completed
- Action: Kevin requests that a written statement by each team member state the desired tasks to be completed each week.
  - The group agrees to have the first weeks goals sent to Kevin by February 17
- Kevin left meeting at 9:20am
- Action: Cody records each team member's goal for the week from February 16 until February 21.
  - Cody tasks:
    - Continue construction of the room mock-up.
    - DConstruct the robot stand based on SolidWorks design.
    - Calculate stresses and factors of safety for robot stand.

APPENDIX LL: Project Update Presentations

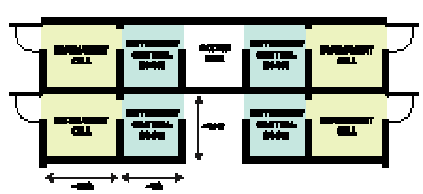
Idaho National Laboratory

Sample Preparation Laboratory Teleoperations (SPLT)

ME 4496A - Fall 2015
Larinda Nichols, Jerron Berrett,
Cody Race, Sage Thibodeau

PROJECT BACKGROUND

- Materials and Fuels Complex at Idaho National Laboratory
- Sample Preparation Laboratory Facility
- Instrumentation Cells



PROBLEM STATEMENT

Capability to load and unload radioactive samples from a transport system to examination equipment remotely.

Idaho National Laboratory

REQUIREMENTS

- Capture of the radioactive sample transfer container from the pneumatic transfer system
- Remove the sample from the sample transfer container
- Open and close (if necessary) the instrument tray
- Place sample in instrument tray
- Retrieve the radioactive sample from the instrument tray
- Return to pneumatic transfer system

Idaho National Laboratory

PRELIMINARY IDEAS

- Master Slave Manipulator
- Armor Suit
- Robotic Arm
- Robotic Rover
- Chute/Conveyor Belt
- Crane/ Claw
- Heli-Quad Copter

Idaho National Laboratory

Update

IDEAS		Master Slave Manipulator		Armour Suit
PROS	5	Tried and True	3	Human Aspect (Placement)
	3	Non-human Contact (Radiation)		
	5	Manuverable	5	Drop/ Pick it up
	5	DOF		
	5	Meets Repeatability Specs		
	2	Non-Programming		
CONS	3	Requires more space	3	Only protects vital organs
	5	Need special viewing (window)		Radiation Hazard
			3	Undeveloped (Time)
	2	Requires specialized operators		
	3	Creates physical stress injuries		
	1	Outdated		
	1	Slower to do simple tasks (10x)		
Total	10		2	

Idaho National Laboratory

Update Continued

Summary

Concept	Score
Master Slave Manipulator	0
Armour Suit	0
Robotic Arm	0
Robotic Rover	0
Chute/Conveyor Belt	0
Crane/ Claw	0
Heli-Quad Copter	0

		Concept				
Spec	Weight	Master Slave Manipulator	Armour Suit	Robotic Arm	Robotic Rover	Chute/Conveyor Belt
	Total	0	0	0	0	0

QUESTIONS?

Sample Preparation Laboratory Teleoperations (SPLT)

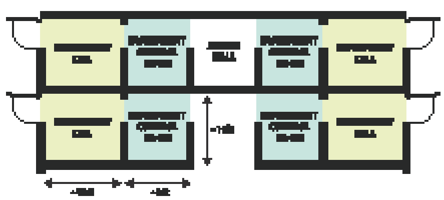
Project Update
10/12/2015

Team Leader: Cody Race
Sage Thibodeau
Jerron Berrett
Larinda Nichols

Idaho State University
College of Science and Engineering

Background

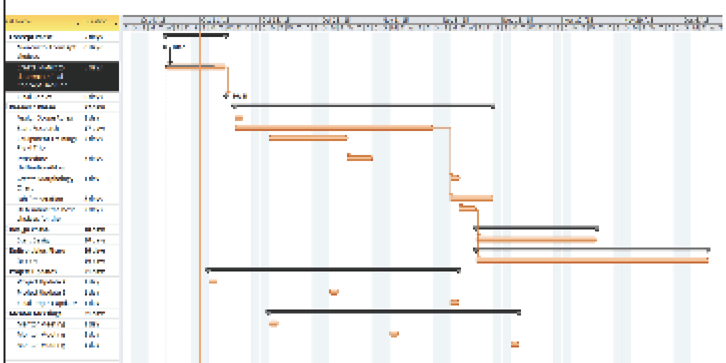
- Materials and Fuels Complex at Idaho National Laboratory
- Sample Preparation Laboratory Facility
- Instrumentation Cells



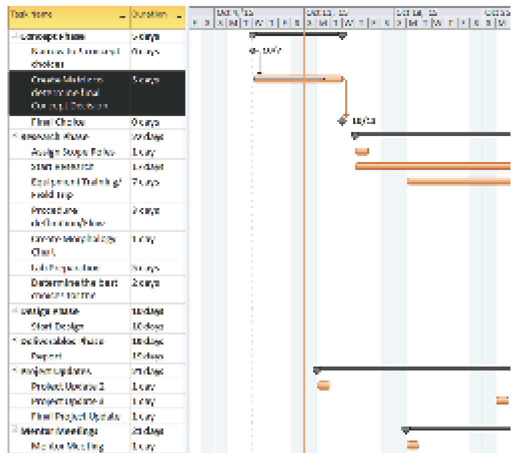
Problem Statement

- Capability to load and unload radioactive samples from a transport system to examination equipment remotely.

Project Timeline



Where we are now!



Requirements & Constraints

- Operate in 10.5' x 8' Cell
- Remove/return of sample to transfer system
- Remove/return sample to container
- Open/close experiment equipment
- Place/retrieve sample from equipment
- React to dropped sample
- Accurate

Requirements & Constraints

- Repeatability
- Multi-personnel operation
- $1x10^6$ Rad absorbed dose
- No sharp edges
- Safety
- 10 year life cycle
- Easy to upgrade/maintenance

Sage Thibodeau Team SPLT

Our new and improved decision matrix

- Using this scale we went through our specifications

Weight	
1	Optional
2	
3	Desired
4	
5	Mandatory

- Then using a 0-5 scale we went through all of our ideas

Jarron Barrett Team SPLT

Decision Matrix

Spec	Weight	Master Slave Manipulator
removal/return of sample from pneumatic transfer system.	5	5
removal/return to rabbit	5	4
removal/return to instruments	5	4
Vision (Optics/window)	3	2
Ability to react to dropped sample	5	5
Accuracy	5	5
Repeatability	5	3
Multi-personel operation (lefty/Righty)	4	2
A total dose of 1 x 10^6 Rad shall be the basis for equipment radiological design (2 Ci Co 60)	5	5
No sharp edges	3	5
Safety	3	3
10 year life cycle	3	5
Easy to Upgrade/ Modular	3	0
Cell Size (10.5' X 8')	4	3
Lifetime Cost	2	1
Complexity	2	5
	Total	217

Jerron Barrett

Team SPLT

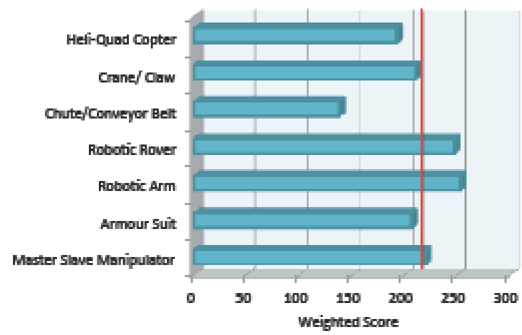
- After going through all of our ideas and adding up the scores we compared all of our ideas and narrowed it down to three

Summary	
Concept	**Score**
Master Slave Manipulator	217
Armour Suit	212
Robotic Arm	253
Robotic Rover	247
Chute/Conveyor Belt	143
Crane/ Claw	216
Heli-Quad Copter	198

Jerron Barrett

Team SPLT

Graphical Representation of Results



Larinda Nichols Team SPLT

Final Three Concepts

1. Robotic Arm
2. Robotic Rover
3. Master Slave Manipulators

Mandatory Requirements Check:

- Removal/return to transfer system
- Removal/return to instruments
- Ability to react to dropped sample
- Accuracy and repeatability
- Perform in radiological environment

Larinda Nichols Team SPLT

QUESTIONS?

Team SPLT

Sample Preparation Laboratory Teleoperations (SPLT)

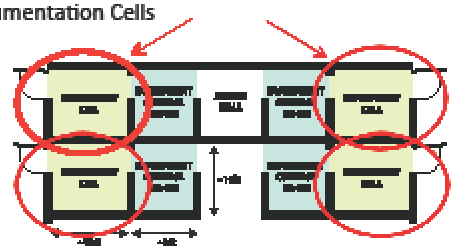
Project Update
10/26/2015

Team Leader: Cody Race
Sage Thibodeau
Jerron Berrett
Larinda Nichols

Idaho State University
College of Science and Engineering

Background

- Materials and Fuels Complex at Idaho National Laboratory
- Sample Preparation Laboratory Facility
- Instrumentation Cells



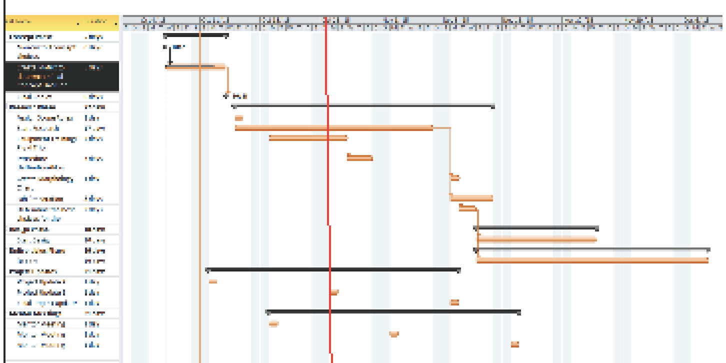
Cody Race   Team SPLT

Problem Statement

- Idaho National Laboratory (INL) needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.

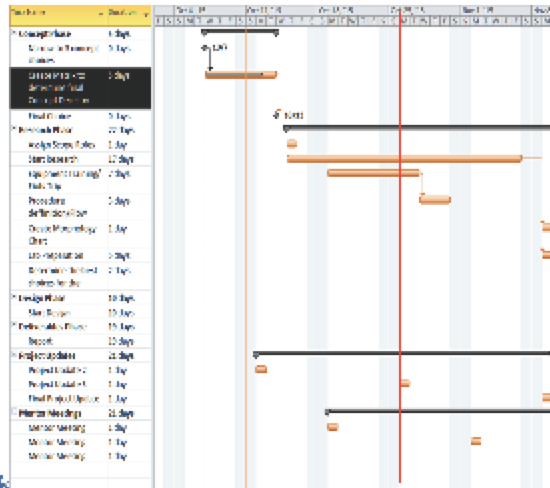
Cody Race Team SPLT

Project Timeline



Cody Race Team SPLT

Where we are now!



Cody Race

Team SPLT

Constraints and Specifications

Constraint		Specification
Removal/return of sample from pneumatic transfer system.		Physically be able to remove and return the sample to the transfer system
Removal/return to rabbit		Physically be able to remove and return the sample too the rabbit
Removal/return to instruments		Physically be able to remove and return the sample to the instruments
Vision (Optics/window)		Physically see inside the room without human being in the room
Ability to react to dropped sample		Physically be able to pick up a dropped sample
Accuracy		System places sample within a 1 inch radius from desired location
Repeatability		System meets the accuracy specification 99% of the time
Multi-personnel operation (lefty/ Righty)		System able to be operated by left and right handed operators

Jerron Barrett

Team SPLT

Constraints and Specifications

Constraints	Specifications
Radiological environment	Equipment should be able to withstand a total absorbed dose of 1 x 10^6 Rad
No sharp edges	Rounded corners when edges are greater then 90 degrees
Equipment Safety	Physically be able to sense when bumps objects as well as be able to be entirely shut down during maintenance
Radiological Safety	Personnel won't have to be in the same room physically while robot is in operation
Endurance	10 year lifecycle
Easy to Upgrade/ Modular	Be able to remove and replace components within 24 hours
Cell Size	Physically maneuvers and reacts to dropped samples within a 10.5' x 8' area
Cost	Does not exceed a value of $200,000
Complexity	Time to completion takes less than 9 months

Jamon Barrett Team SPLT

Preliminary Ideas

- Master Slave Manipulator (1)
  - Currently used mechanically controlled arm
- Armor Suit (2)
  - Radiation protection for human entering environment
- Robotic Arm (3)
  - Teleoperated/automated control arm
- Robotic Rover (4)
  - Mobile vehicle equipped with control arm

Jamon Barrett Team SPLT

Preliminary Ideas

- Chute/Conveyor Belt (5)
  - "Treadmill" or slide transport system to instruments
- Crane/ Claw (6)
  - Overhead maneuverable claw
- Heli-Quad Copter (7)
  - Flying delivery system

Decision Matrix

Spec	Weight	Concept						
		1	2	3	4	5	6	7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Master Slave Manipulator	1
Armour Suit	2
Robotic Arm	3
UGV	4
Chute/Conveyor Belt	5
Crane/ Claw	6
Heli-Quad Copter	7

- After going through all of our ideas and adding up the scores we compared all of our ideas and narrowed it down to three

Summary	
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Master Slave Manipulator	217
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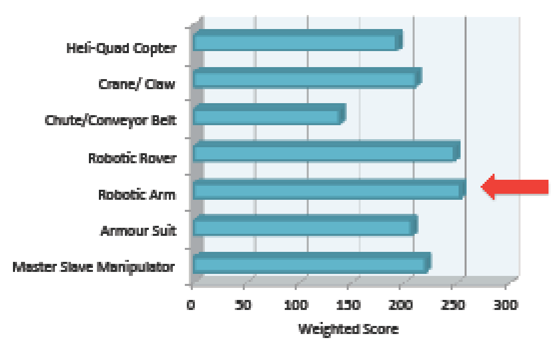
Crane/ Claw	216
Heli-Quad Copter	198

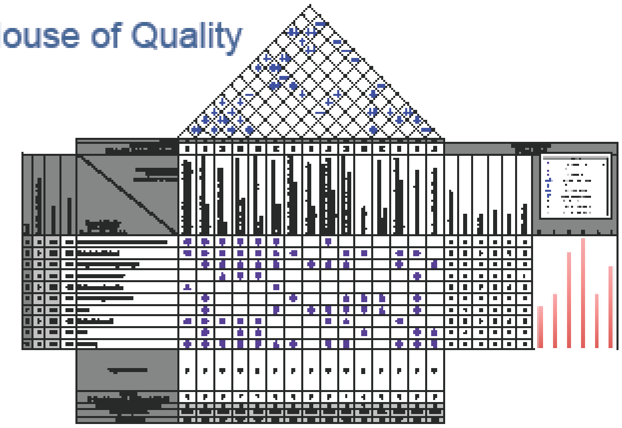
Team SPLT

Results of Decision Matrix



Team SPLT

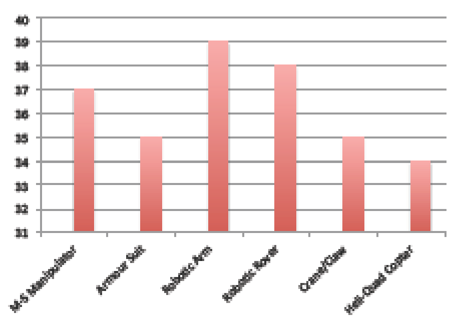
House of Quality



Larinda Nichols

Team SPLT

Results Using House of Quality



Larinda Nichols

Team SPLT

Choice of Final Concept

Robotic Arm

1. Scored highest on Decision Matrix
2. Highest correlation on House of Quality
3. Viable solution to problem statement

Larinda Nichols

Team SPLT

Procedure

- Rabbit enters hot cell through transfer system
- Sense sample entry to hot cell
- Open/Prepare instrumentation for acceptance of sample
- Open transfer system door
- Grab rabbit with robotic arm
- Open Canister

Sage Thibodeau

Team SPLT

Procedure

- Locate sample in rabbit
- Retrieve sample from rabbit
- Orient sample to be placed in instrument
- Place sample in instrument
- Close instrument door
- Close transfer system door
- Return to "standby position"

Return Procedure

- Open transfer system door
- Open instrumentation door
- Retrieve sample
- Orient sample for return into rabbit
- Place sample into rabbit
- Close rabbit

Return Procedure

- Place rabbit into transfer system
- Close transfer system door
- Send sample back through transfer system

Sage Thibodeau Team SPLT

QUESTIONS?

Team SPLT

Sample Preparation Laboratory Teleoperations (SPLT)

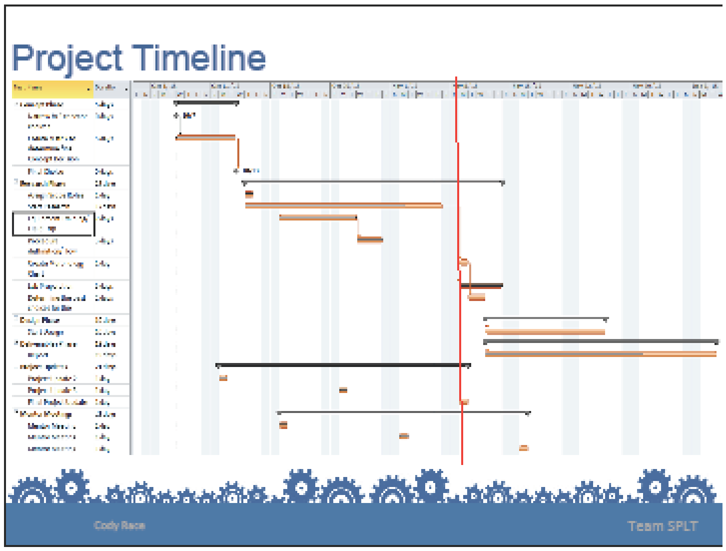
Project Update
10/26/2015

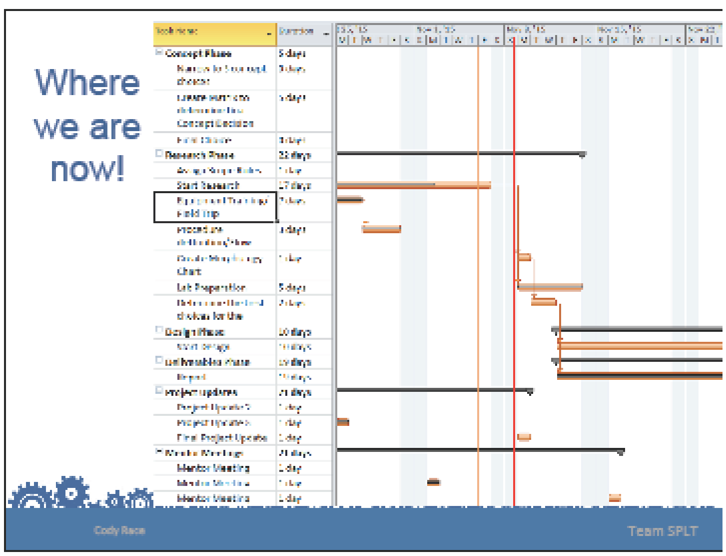
Team Leader: Cody Race
Sage Thibodeau
Jerron Berrett
Larinda Nichols

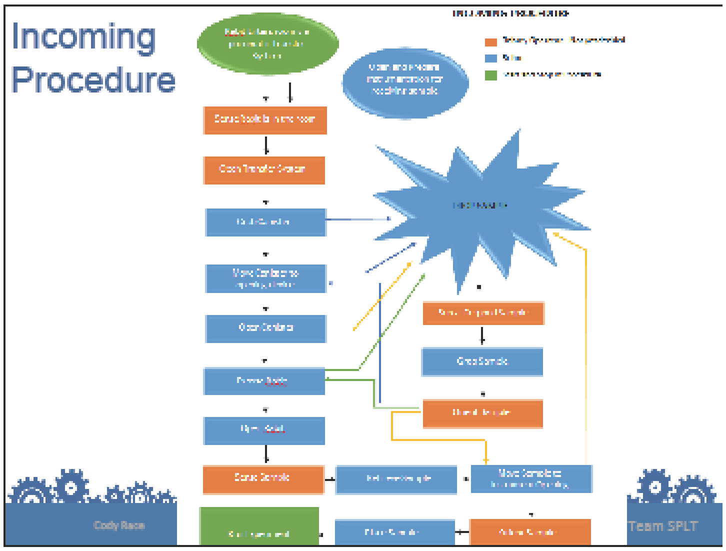
Idaho State University
College of Science and Engineering

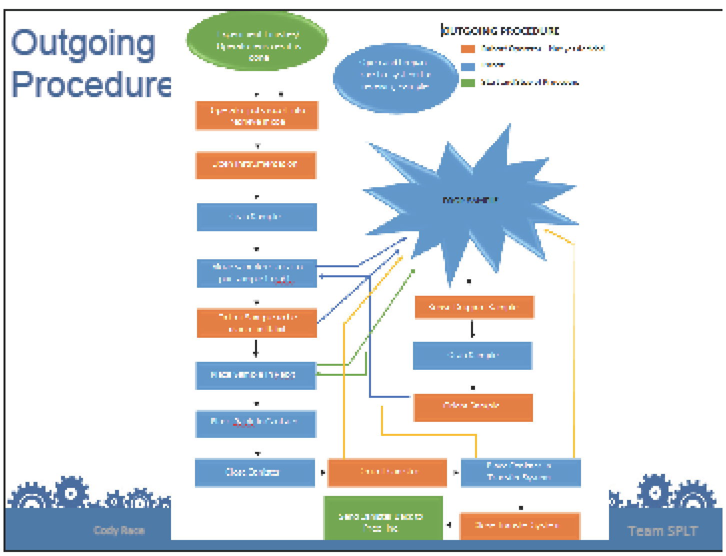
Problem Statement

- Idaho National Laboratory (INL) needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.

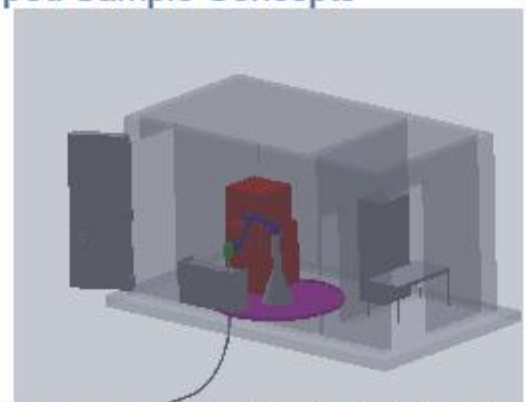

Project Timeline
Cody Race
Team SPLT


Where we are now!
Concept Phase
Research Phase
Start Research
Lab Preparation
Design Phase
Deliverables Phase
Project Updates
Mentor Meetings
Mentor Meeting
Cody Race
Team SPLT


Incoming Procedure
Cody Race
Team SPLT


Outgoing Procedure
OUTGOING PROCEDURE
Cody Race
Team SPLT

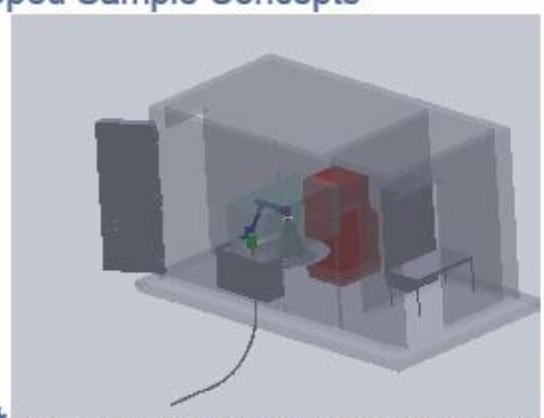
Dropped Sample Concepts



Cody Race

Team SPLT

Dropped Sample Concepts

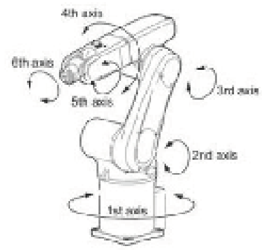


Cody Race

Team SPLT

Degrees of Freedom of a Robotic arm

- Degrees of freedom refers to the number of single-axis rotational joints
- These axes allow the robot to move in the orientation it needs to get a job completed
- This picture shows the degrees of freedom
- Most Robotic arms have 6 degrees of freedom



Size of the Robot

- We are currently looking into the size of the robot we will choose to use for our application
- The size is contingent on a few things: the size of the room, placement of the instrumentation, and where the sample will be coming into the room
- Another deciding factor for the size is how we will be dealing with the chance of a dropped sample

Material Considerations

- Materials must retain their functionality and integrity
- Effectiveness of radiation absorption or resilience
    - Depends largely on molecular cross section
    - High electron density = most effective shielding
    - Hydrogen has highest electron density of any atom
- Selection should be fiscally appropriate

Larinda Nichols Team SPLT

Material Considerations - Containment

- Polymers have highest hydrogen content
- Poly methyl methacrylate (PMMA) a.k.a. "Plexiglas"
- Often used as a safety glass
- Inexpensive
- Highly scratch resistant and workable
- Transmits up to 92% of visible light (3mm thickness)
- Reflection of only about 4%
- Effective shield for beta radiation
- Can be leaded to included gamma shielding (cost)

Larinda Nichols Team SPLT

Material Considerations - Tray

- Stainless steel is common in nuclear environments
  - Corrosion resistant
  - Stronger than other metals
  - Can be used in high temperature settings
- Moisture and high temperatures are not factors
  - Aluminum is less expensive
  - More workable
  - Lighter
- Aluminum: adequate and less expensive for this application

Sensors

Performance Characteristics

- Resolution
- Accuracy
- Repeatability
- Interference/Noise
- Bandwidth

States to be Sensed

- Sample has entered room
- Locate sample in rabbit
- Orientation of sample
- Dropped sample
- Location of dropped sample

Sage Thibodeau Team SPLT

Types of Sensors

- Ultrasonic sensors
- Photocells
- Position Sensitive Devices
- IR emitter/detectors
- Tilt Sensors
- Force Gauges
- Switches

Sage Thibodeau Team SPLT

Loaner Robot!

Loaner Robot!

Checking for Accuracy and repeatability

QUESTIONS?

Team SPLT

Sample Preparation Laboratory Senior Design Project

IDAHO STATE UNIVERSITY
ME 4496

January 22nd, 2016

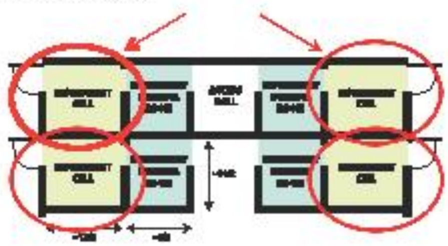
Cody Race
Larinda Nichols
Jerron Berrett
Sage Thibodeau

Mentor: Kevin Croft – Sr. Advisory Engineering, INL

www.inl.gov

Background

- Materials and Fuels Complex at Idaho National Laboratory
- Sample Preparation Laboratory Facility
- Instrumentation Cells



Cody Race

Senior Design Project

- **PROBLEM STATEMENT:**

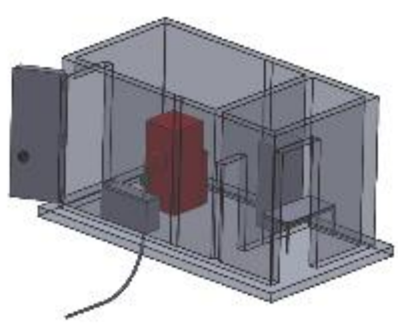
  INL needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.

- **OBJECTIVE:**

  Investigate the integration of kinematics, electronics, material sciences and radiation physics for the design of a system for use in a nuclear hot cell environment.

Cody Race

Conceptual Design – Instrumentation Cell



Cody Race

Constraints & Specifications

- ACCURACY
  - System must place sample within a 0.004 in. radius from the desired location
- REPEATABILITY
  - System must meet the accuracy specification 99% of the time
- RADIOLOGICAL ENVIRONMENT
  - Equipment must be able to withstand up to $1x10^8$ Rad exposure
- RADIOLOGICAL SAFETY
  - Personnel shall not be physically present in the cell during operation
- OVERALL COST OF PROJECT
  - Must meet a budget of $50,000
- COMPLEXITY
  - Project Study to be completed within 9 months (May 2016)

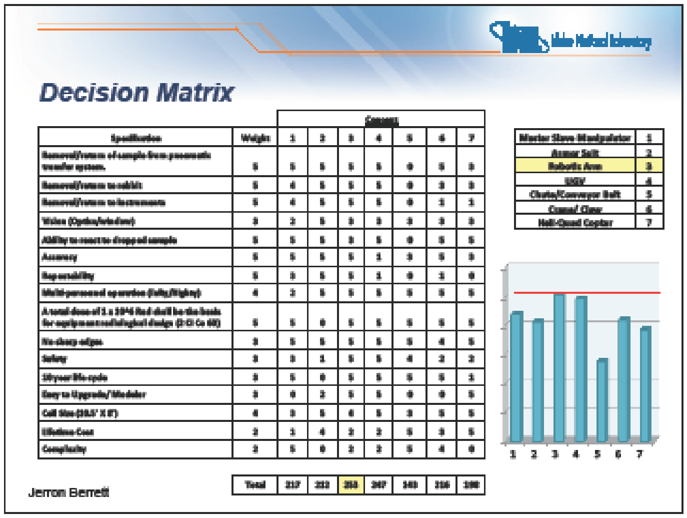
Cody Race

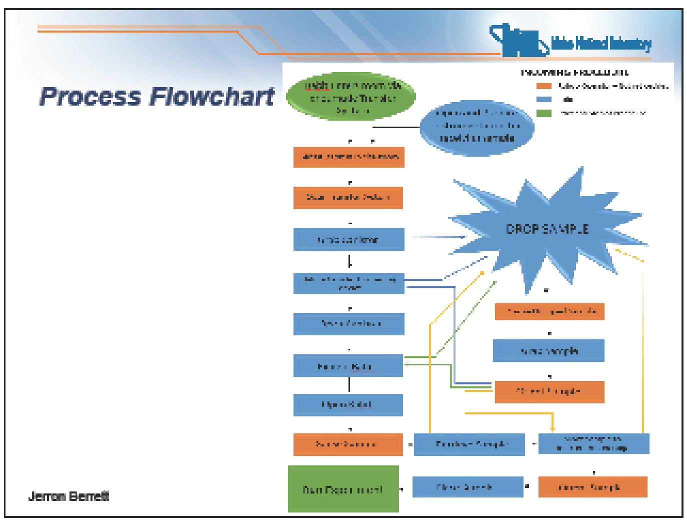
Preliminary Ideas

1. MASTER SLAVE MANIPULATOR
2. ARMOR SUIT
3. ROBOTIC ARM
4. ROBOTIC ROVER
5. CHUTE/CONVEYOR BELT
6. CRANE CLAW
7. HELI-QUAD COPTER

Cody Race

3


Decision Matrix
Master Slave Manipulator
Robotic Arm
UGV
Chute/Conveyor Belt
Heli-Quad Copter
Jerron Berrett


Process Flowchart
DROP SAMPLE
Jerron Berrett

4

Current Work

- Considerations for final choice of robotic system
  - Reach
  - Payload
  - Flexibility / Degrees of freedom
  - Cost
- Universal Robots
  - Easily programmable
  - Fast initial setup
  - Flexible deployment
  - Collaborative and safe

Jerron Berrett

Current Work

(a) UR-3 (b) UR-5 (c) UR-10

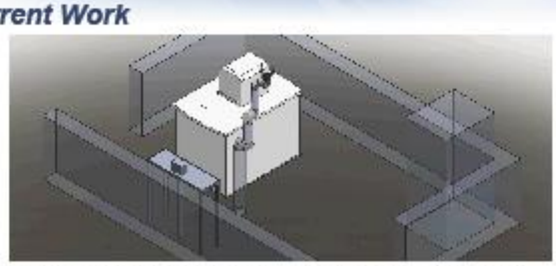
Jerron Berrett

Current Work

Mock-up of Instrumentation Cell at MCERC

Jerron Berrett

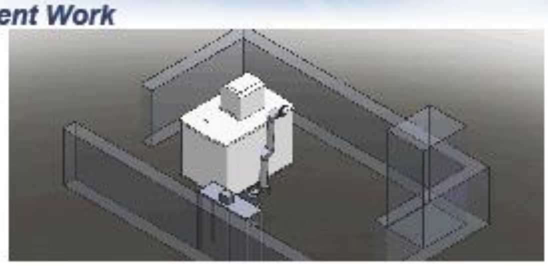
Current Work



- SolidWorks simulation of UR-5 in motion (not entire procedure)
- Position of robotic arm
  - 12 inches right of PFIB table*
  - 4 inches down from the PFIB table*
  - Height: Base of the robot is at base of PFIB table
  - * (Based on Top View)

Sage Thibodeau

Current Work



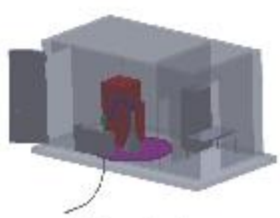
- SolidWorks simulation of UR-10 in motion (not entire procedure)
- Position of robotic arm
  - 30 inches right of PFIB table*
  - 4 inches down from the PFIB table*
  - Height: Base of the robot is 12 inches from floor

  - *(Based on Top View)

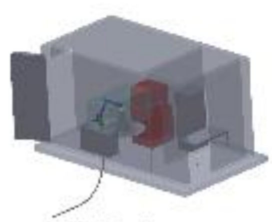
Sage Thibodeau

Current Work

DROPPED SAMPLE CONCEPTS



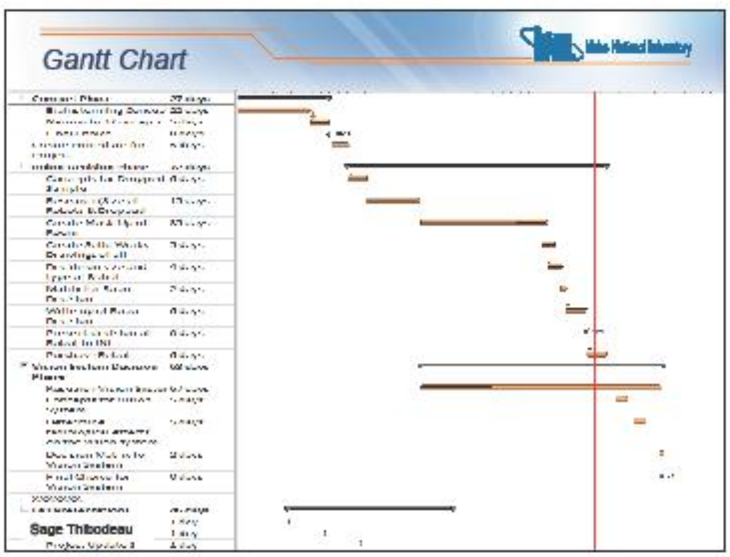
(a) Tray System



(b) Enclosure

Sage Thibodeau


Idaho National Laboratory
Current Work
Vision system set up in our Lab
– 3-D vision
Plan: Set up 2-D cameras as a control
The EYES!
What the eyes SEE!
Sage Thibodeau


Idaho National Laboratory
Gantt Chart
Sage Thibodeau

8

Plan Going Forward

- Solidify decision and procure necessary components
  - Robot size
  - Vision system
  - Electronic sensors
  - Additional materials required
  - Complete analysis of system
- Determine retrieval and replacement of sample to/from RABIT
- Determine a solution to the off-normal situation
  - If a sample is dropped, how does the robot retrieve it?

Sage Thibodeau

Questions?

9

Sample Preparation Laboratory Senior Design Project Update

IDAHO STATE UNIVERSITY
ME 4496

February 8th, 2016

Cody Race
Larinda Nichols
Jerron Berrett
Sage Thibodeau

Mentor: Kevin Croft – Sr. Advisory Engineering, INL

www.inl.gov

Senior Design Project

- **PROBLEM STATEMENT:**

  INL needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.

- **OBJECTIVE:**

  Investigate the integration of kinematics, electronics, material sciences and radiation physics for the design of a system for use in a nuclear hot cell environment.

Larinda Nichols

1

Summary of Design

- Main Components
  - Mock-up of instrumentation cell
  - Mock-up of transfer system
  - Robot arm
  - Enclosure system
  - Electronic sensors
  - Vision system

Larinda Nichols

Current Work

- Mock-up of Instrumentation Cell
  - Initially made from cardboard
  - Requested to use plywood for demonstration purposes.
  - Will include doorways, instruments, and cabinetry
  - Stand design required for mounting robot arm
  - Overall cost to date: $1,000

Jerron Barrett

Current Work

- **Mock-up of Transfer System**
  - To be located based on robot placement
  - Constructed from PVC and Plexi-glas
  - Cost of transfer system included in previous slide

Jerron Barrett

Current Work

- **Purchase of Robotic Arm**
  - Universal Robot UR-5
  - Robotiq Gripper
  - Estimated delivery within the week
  - Final Cost: $31,177

Jerron Barrett

Current Work

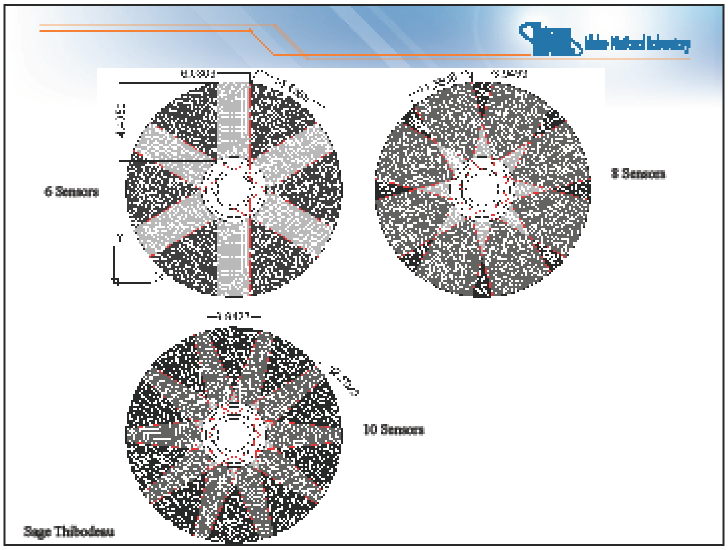
- **Enclosure System**
  - Full robot enclosure
  - Transferable "glove"
  - Tray
  - Meeting scheduled to discuss options with operators
  - Final system will be based on decision matrix
  - Cost to be determined

Sage Thibodeau

Current Work

- **Dropped Sample Sensors**
  - PIR Motion Sensors
  - 30 ft range
  - 120 degree range of sight
  - Analysis of optimum number and configuration for detection

Sage Thibodeau



Idaho National Laboratory

Current Work

- **Vision System**
  - Stereo vision vs. 2-D cameras
  - Testing once mock-up is in place
  - Final system will be based on decision matrix

Cody Race

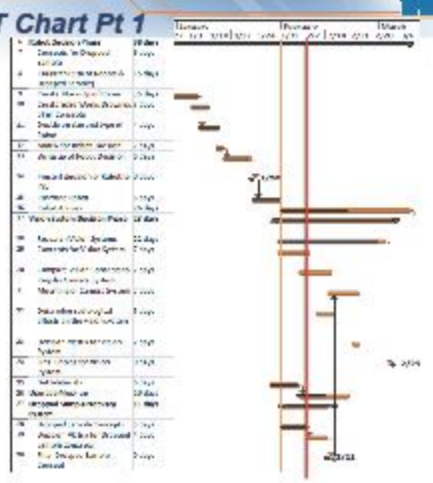
5

Plan Moving Forward

- Complete all in-progress work
  - Finish mock-ups
  - Install robotic arm
  - Construction of enclosure
  - Finalize sensors and camera system
- Evaluate final design
  - Test process
  - Troubleshoot off-normal situations
  - Make additional recommendations as needed
- Finalize all deliverables

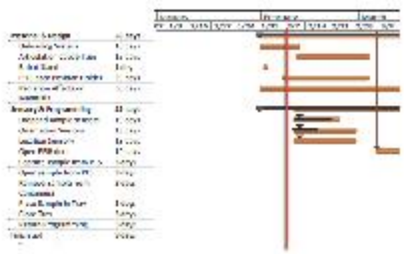
Cody Race

GANTT Chart Pt 1



Cody Race

GANTT Chart Pt 2



Cody Race

Updated Budget

Item	Cost	Comments
Robotic Arm	$ 25,600.00	
Gripper	$ 4,320.00	
Robot Shipment	$ 1,257.00	
Mock-up Materials	$ 1,000.00	Estimate
Sensors	$ 40.00	
Vision System	----	TBD
Total Spent	$ 32,217.00	
Budget	$ 50,000.00	
Remaining	$ 17,783.00	

Larinda Nichols

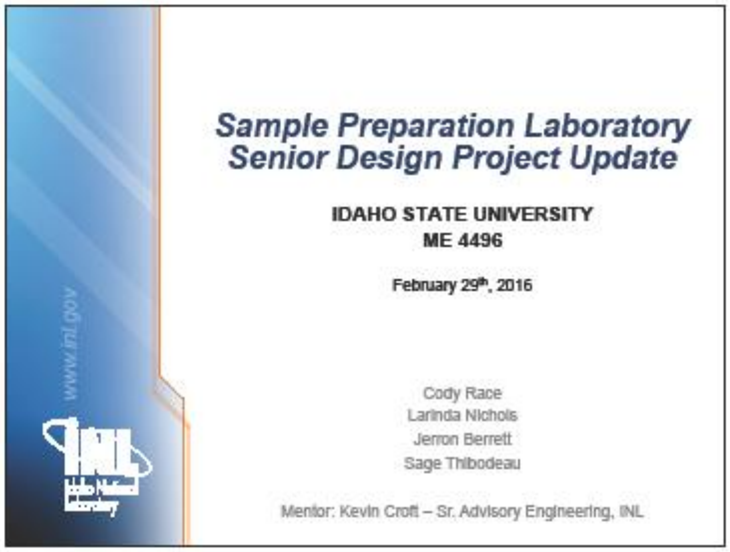
Deliverables

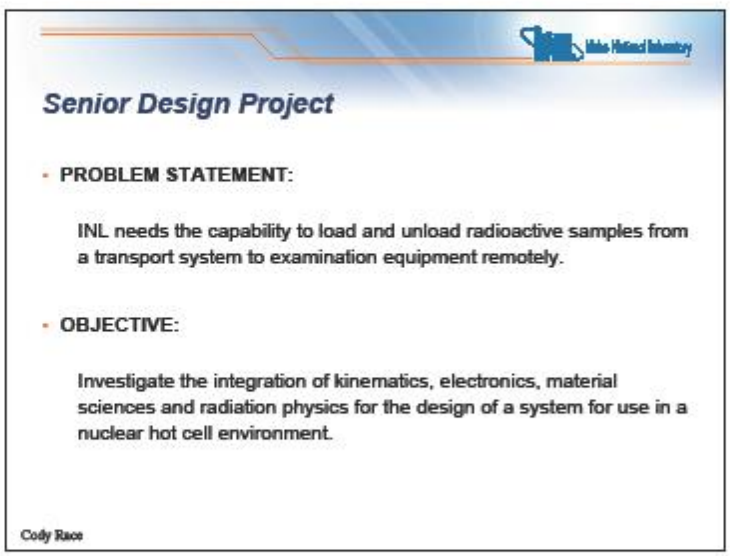
1. Instrument Cell Mock-up
2. Recommendations for Final System
   - Robot
   - Vision System
   - Electronic Sensors
   - Enclosure
3. Drop Sample Solutions
4. Final Presentation at ISU on April 20th
5. Final Presentation to INL
6. Final Report Due April 27th

Larinda Nichols

Questions?

8


Sample Preparation Laboratory
Senior Design Project Update
IDAHO STATE UNIVERSITY
ME 4496
February 29th, 2016
Cody Race
Larinda Nichols
Jerron Berrett
Sage Thibodeau
Mentor: Kevin Croft – Sr. Advisory Engineering, INL
www.inl.gov
Idaho National Laboratory


Idaho National Laboratory
Senior Design Project
PROBLEM STATEMENT:
INL needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.
OBJECTIVE:
Investigate the integration of kinematics, electronics, material sciences and radiation physics for the design of a system for use in a nuclear hot cell environment.
Cody Race

Individual Responsibilities

Task		Start	Finish	Completion (%)
Cody's Responsibilities	50 days	Mon 1/11/16	Fri 3/18/16	57%
Simulators	8 days	Mon 1/11/16	Wed 1/20/16	100%
Room Mock up	15 days	Mon 2/1/16	Fri 2/19/16	95%
Robot Stand	10 days	Mon 2/8/16	Fri 2/19/16	100%
Calculations for Design	10 days	Mon 2/8/16	Fri 2/19/16	100%
Pan Tilt Unit	5 days	Mon 2/15/16	Fri 2/19/16	100%
Machine Vision	6 days	Mon 2/22/16	Mon 2/29/16	50%
Radiation Effects on Camera system	10 days	Mon 2/22/16	Fri 3/4/16	25%
2-D to 3-D comparison	10 days	Wed 2/24/16	Tue 3/8/16	0%
Placement of vision system to Robot	5 days	Mon 2/29/16	Fri 3/4/16	5%
Placement of room Cameras	5 days	Mon 2/29/16	Fri 3/4/16	5%
Carrier Design	10 days	Mon 3/7/16	Fri 3/18/16	0%

Cody Race

Completed Work

- Robot Stand (100%)
  - Designed and welded stand to hold the robot
  - Factor of safety for moment loads and compressive loads >> 5
- Pan Tilt Unit (100%)
  - Needed a way to track up and down
  - Looked at 3 options
    - Wild Shot Camera CPT 1019 Pan Tilt System
    - COBRACRANE PROLINE Pan Tilt System
    - Wild Shot Camera MPT1022 Mini Motorized Pan & Tilt Unit
  - Decided to go with MPT1022
    - Small Profile
    - Easier to mount

- Machine Vision (50%)
  - Allow a way to orient samples before placement
  - Working with Sage on integration

Cody Race

2

Next Steps

- Machine Vision
  - Radiation effects
    - Determine the life of the cameras being so close
    - $3,000 camera at least 5 year lifetime
  - Budget (waiting on the numbers!)
    - Cost $5,000
    - Roughly $8,000 left (complete budget shown later)
- 3-D vs 2-D
  - Waiting on cables to be able to run dual monitors
- Placement on Robot
  - Waiting on basic program to be complete to determine the movement needed of camera system
  - Will be tracked like a human shoulder for ease of operation
- Placement of room camera
- Carrier Design

Cody Race

Individual Responsibilities

Task		Start	Finish	Completion (%)
Larinda's Responsibilities	30 days	Mon 2/1/16	Fri 3/11/16	46%
Tray Design and Dropped Sample Concepts	30 days	Mon 2/1/16	Fri 3/11/16	75%
Radiation Effects on Material	20 days	Mon 2/15/16	Fri 3/11/16	55%
Enclosure Simulation of Concepts	9 days	Tue 2/16/16	Fri 2/26/16	80%
Bolt Calculations	15 days	Mon 2/22/16	Fri 3/11/16	0%
Carrier Design	5 days	Mon 3/7/16	Fri 3/11/16	0%

Larinda Nichols

3

Work in Progress

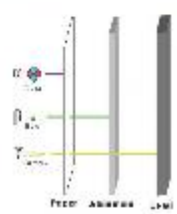
- **Tray Design (75%)**
  - Aluminum
  - Must extend to encompass robot reach
  - Must not interfere with instrument access

- **Enclosure Concepts (75%)**
  - Four options using acrylic

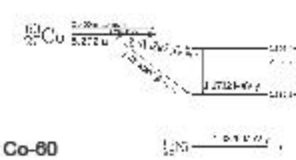
- **Dropped Sample Concepts (50%)**
  - Incorporation of tray design and enclosure
  - Troubleshooting possibilities
- **Radiation Effects on Materials (35%)**
  - Exposure, attenuation
  - Activity, absorption

Next Steps

- **Construction for Mock-up**
  - Aluminum tray
  - Transfer system carrier



- **Present Enclosure Concepts to INL**
  - PowerPoint for project engineers
  - Awaiting response/input
  - Construct final enclosure (acrylic)
- **Troubleshooting and Testing**
  - Dropped sample
  - Tray & enclosure testing



- **Complete & Verify All Calculations**
  - Beta & Gama radiation, based on Co-60

Individual Responsibilities

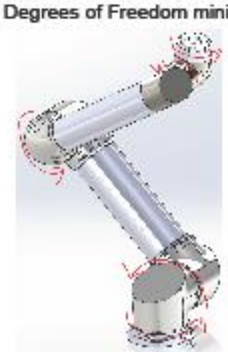
Task		Start	Finish	Completion (%)
Jerron's Responsibilities	[illegible] days	Mon 12/21/15	Thu 3/31/16	[illegible]
Robot Study	23 days	Mon 12/21/15	Wed 1/20/16	100%
Minimum DOF	41 days	Fri 1/1/16	Fri 2/26/16	100%
Reach Schematic of Robot	20 days	Mon 2/1/16	Fri 2/26/16	100%
Transfer System for Mock Up	10 days	Mon 2/22/16	Fri 3/4/16	0%
Corner Design	10 days	Wed 2/24/16	Fri 3/18/16	0%
Actuation Tools if Needed	14 days	Mon 3/14/16	Thu 3/31/16	0%

Jerron Barrett

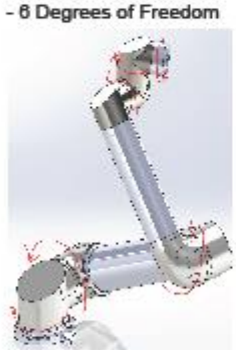
Completed work

- Minimum DOF (100%)

- 5 Degrees of Freedom minimum

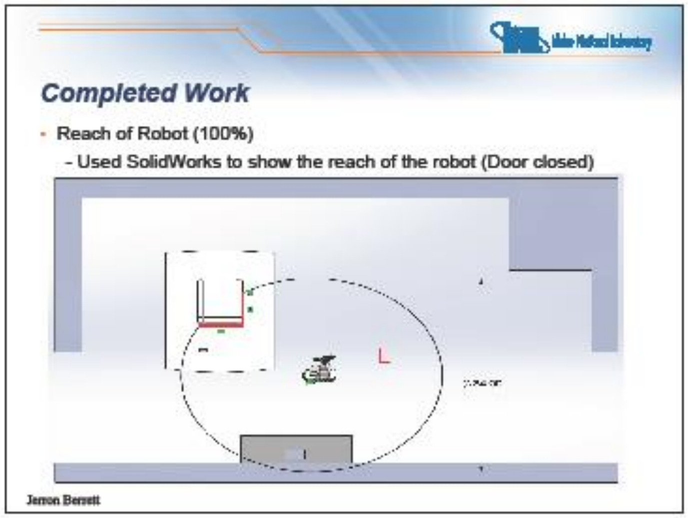


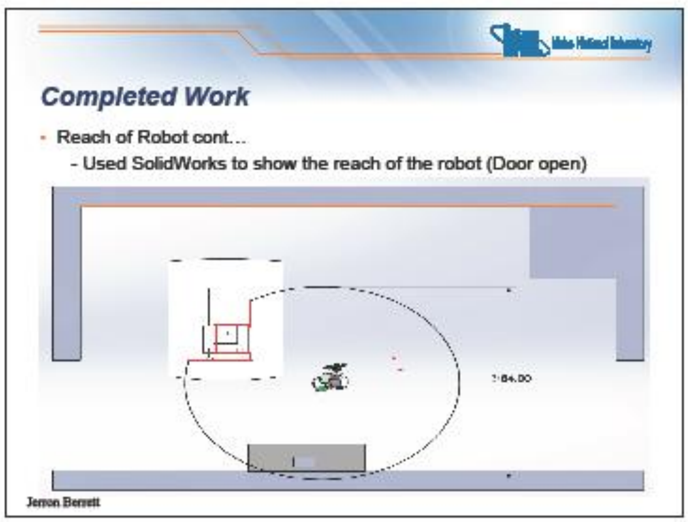
- 6 Degrees of Freedom



Jerron Barrett

5


Completed Work
Reach of Robot (100%)
- Used SolidWorks to show the reach of the robot (Door closed)
Jerron Berrett


Completed Work
Reach of Robot cont…
- Used SolidWorks to show the reach of the robot (Door open)
Jerron Berrett

Next Steps

- Transfer system for mock up
- Carrier holder design
- Articulation tools

Jerron Berrett

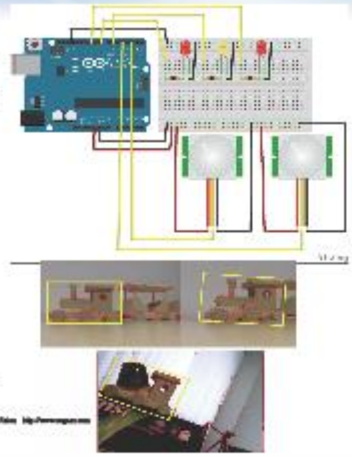
Individual Responsibilities

Task		Start	Finish	Completion (%)
Sage's Responsibilities	50 days	Mon 2/8/16	Fri 4/15/16	19%
Dropped Sample Sensor	15 days	Mon 2/8/16	Fri 2/26/16	100%
Machine Vision	6 days	Mon 2/22/16	Mon 2/29/16	50%
Basic Procedure Programming	14 days	Tue 2/23/16	Fri 3/11/16	10%
Orientation Sensory	8 days	Wed 2/24/16	Fri 3/4/16	75%
Location Sensory	4 days	Wed 2/24/16	Mon 2/29/16	0%
Electronics manipulation	16 days	Wed 2/24/16	Wed 3/16/16	0%
Gripper Integration	10 days	Mon 2/29/16	Fri 3/11/16	0%
Integration of Sensory	8 days	Wed 3/2/16	Fri 3/11/16	0%
In Depth Procedure	14 days	Mon 3/14/16	Thu 3/31/16	0%
Troubleshooting and final adjustments	11 days	Fri 4/1/16	Fri 4/15/16	0%

Sage Thibodeau

Completed

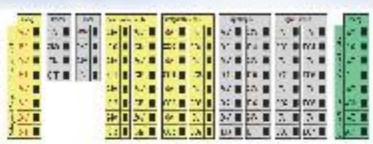
- Dropped Sample Sensor Testing (100%)
  - Used Arduino Microcontroller to test functionality of two PIR motion sensors
  - Basic C language code used to incorporate both sensors
- Location and Orientation of Sample (25%)
  - Experimented with color sensor to achieve correct orientation
  - Did not meet requirements
  - Machine vision provides more precision and utility
- Experimental Programming with UR 5 Robot (10%)
  - Developed basic movement program for UR 5



Sage Thibodeau

Next Steps

- Create program for UR 5 based on preliminary procedure
  - Assume normal operation without dropping sample
- Integrate sensors into UR 5
  - Utilize UR 5 digital inputs
  - Requires 24V to 5V reduction circuit
- Incorporate machine vision into UR 5
  - Will allow robot to orient itself under changing circumstances
- Refine procedure and programming of the robot
  - Make final adjustments and make sure all components work seamlessly



Sage Thibodeau

Budget

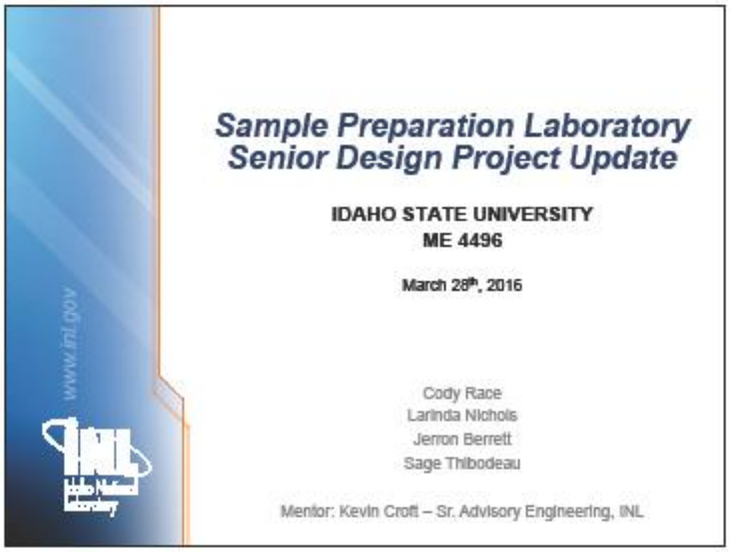
Item	Qty	Cost/Qty	Total Cost
Robot			
UR 5	1	$ 25,600.00	$ 25,600.00
Robotic Gripper	1	$ 4,320.00	$ 4,320.00
Shipping	1	$ 1,600.00	$ 1,600.00
Mock-Up Material			
2x4x8 Lumber	22	$ 2.57	$ 56.54
Plastic Wing Nut	2	$ 13.14	$ 26.28
Acrylic Tubing	3	$ 36.88	$ 110.64
Wafer Board 4x8x3/8	16	$ 10.75	$ 172.00
Grabber Screws 1.5"	3	$ 4.80	$ 14.40
2x4x12 Lumber	5	$ 4.72	$ 23.60
Acrylic Tubing	3	$ 36.18	$ 108.54
Drawer Slides	1	$ 60.07	$ 60.07
Wing Nut	2	$ 14.74	$ 29.48
4x8x1/8 acrylic Sheet	2	$ 137.02	$ 274.04
1x2x8 Lumber	20	$ 2.57	$ 51.40
Scissors	2	$ 19.52	$ 39.04
Duct Tape & Misc.	1	$ 31.72	$ 31.72
Robot Stand			
3.5" schd 40 Pipe	1	$ 20.79	$ 20.79
4" schd 40 Pipe	1	$ 24.05	$ 24.05
1/4x12 12"	1	$ 14.00	$ 14.00
1/4x6" x 6"	1	$ 10.00	$ 10.00
Vision System			
Pan Tilt Unit	1	$ 398.95	$ 398.95
Rvision Power Supply	1	$ 300.00	$ 300.00
Rvision Cables	2	$ 200.00	$ 400.00
Composite to VGA Converter	2	$ 46.00	$ 92.00
RCA to BNC Adapter	2	$ 5.00	$ 10.00
RCA to RCA Cable	2	$ 10.00	$ 20.00
RCA to RCA Adapter	2	$ 5.00	$ 10.00
Kevin Travel			
Rental Cars	8	$ 150.00	$ 1,200.00

Total Budget
$ 50,000.00
Total Spent
$ 35,021.54
BEA's Cut
$ 2,354.52
Budget Left
$ [illegible]

Sage Thibodeau

Questions?

9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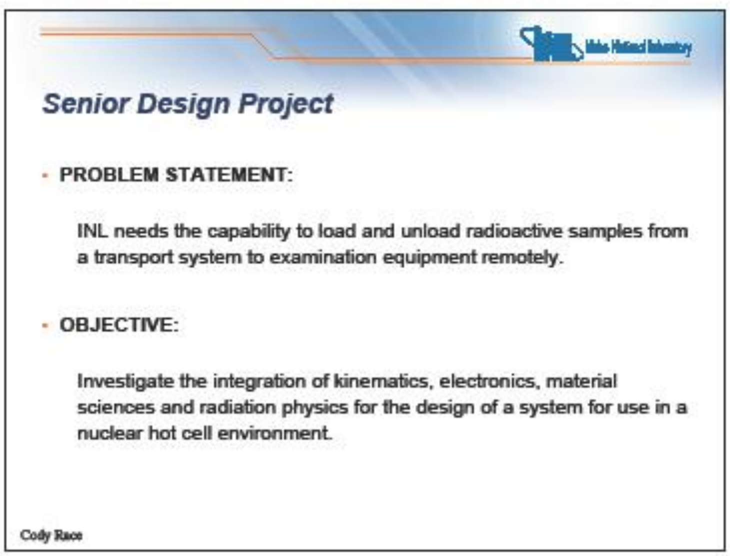
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Cody Race

1

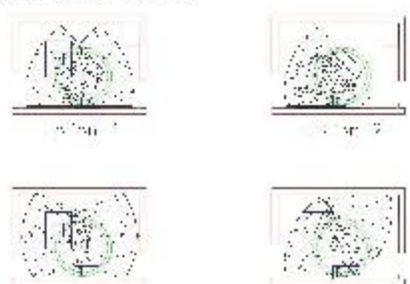
Individual Responsibilities

[illegible]

Cody Race

Current Work

- Position of Room Cameras (~87%)
  - Top View of possible room camera layouts (100%)
  - Download of Software to run cameras (100%)
  - Determine positioning (60%)



Cody Race

Current Work

- Design of Mounting Bracket for Stereovision (45%)
  - Areas of Concern
    - Where to mount camera
      - Payload (5 kg)
    - Stability
    - Able to Track Gravity (stay parallel)
    - Stereovision Functionality now
      - Have Machine Vision
        - Autonomous
      - When will we need it?
  - Initial Concepts
    - Clamp at Base
    - Clamp below Joint 3

Cody Race

Current Work

Initial Concepts

Cody Race

Next Steps

- Determine compromise with Machine Vision and Stereovision
  - Find a location of mounts to be able to co-exist
  - Don't want to lose functionality of either vision system
- Finish design for Stereovision mount
  - Draw up final concept and dimension
  - Get 3-D printed and assembled
- Mount Stereovision
  - Attach Pan-Tilt Unit
  - Calibrate camera system
- Run 2-D vs. 3-D test
- Determine Operator station
- Radiation Effects

Cody Race

Individual Responsibilities

Priority Rank	Task	Status	Date	Remark
	Larinda's Responsibilities	[illegible]		
	[illegible]	100%	[illegible]	
1	[illegible]	100%	[illegible]	
4	[illegible]	0%		[illegible]
1	[illegible]	0%		
1	[illegible]			
	[illegible]	100%	[illegible]	
	[illegible]	100%	[illegible]	
	[illegible]	100%	[illegible]	
	[illegible]	100%	[illegible]	
3	[illegible]	30%	[illegible]	
3	[illegible]	30%	[illegible]	
2	[illegible]	0%		Spring Break?
4	[illegible]	0%		Spring Break?

Larinda Nichols

4

Current Work

- Build of Carriers
  - Created the Larger outside carrier and smaller inside carrier
  - Designed to have a flip top that allows the robot to open with ease
- Sew Curtains
  - Make mock-up a little more presentable
  - Help with the vision system to allow a more realistic viewing of cameras
- Radiation Effects
  - Determined that the materials being used would be affected very little by radiation
  - 1 Ci of Co 60 is not enough to cause large material effects
  - Infinite life determined

Larinda Nichols

Next Steps

- Finish up enclosure ideas for INL proposal
- Paint Mock-Up
  - Make mock-up a little more presentable for INL visit
  - Colors will be earth tones
- Poster Design

Larinda Nichols

Individual Responsibilities

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]		
1	[illegible]	[illegible]		
	[illegible]	[illegible]		
2	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]		
1	[illegible]	[illegible]		
3	[illegible]	[illegible]	[illegible]	
2	[illegible]	[illegible]		
5	[illegible]	[illegible]		

Jerron Barrett

Current Work

- Build Table for mock up
  - Placement of transport system box
  - Placement of Carrier holder
- Make sure robotic arm will be able to perform tasks it needs to with the placement of both of these parts, so there is no interference

Jerron Barrett

6

Current Work

- Carrier Holder
  - Needed a way to hold the carriers when they were not in use
  - The design is two circular holders connected at the base
  - O-rings on the outside of the holders that have tabs
  - The tabs apply friction to the carries to help hold in place
  - Getting this part printed on 3-D printers (excluding O-rings)

Jerron Barrett

Next Steps

- Figure out Placement for transfer system and carrier holder
- Articulation tools
  - Need a way to grab the sample if it is dropped inside of instrumentation where the robotic arm would not be able to grasp it

Jerron Barrett

7

Idaho National Laboratory

Individual Responsibilities

Priority Rank	Task	Status	Date	Remarks
[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]		

Sage Thibodeau

Idaho National Laboratory

Current Work

- Machine Vision (5%)
- Cognex In-sight 1100
- Used to determine orientation/position
- Allows for automation of robot

Cognex In-sight 1100 https://www.vision-supplies.com

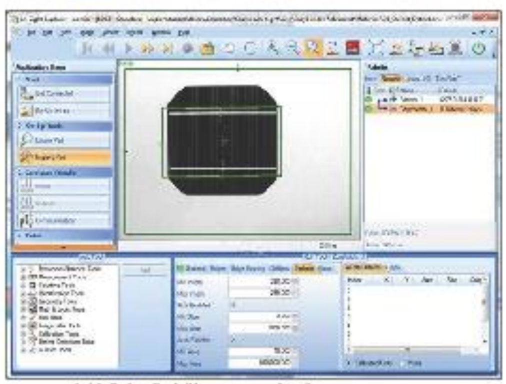
Sage Thibodeau

Current Work

- Two interfaces for vision system
  - Easybuilder
  - Spreadsheet
- Easybuilder
  - Quick and easy
  - No programming or spreadsheets needed
- Spreadsheet
  - Set up like an Excel spreadsheet
  - Allows for full control of vision system
  - Provides access to complex logic statements

Sage Thibodeau

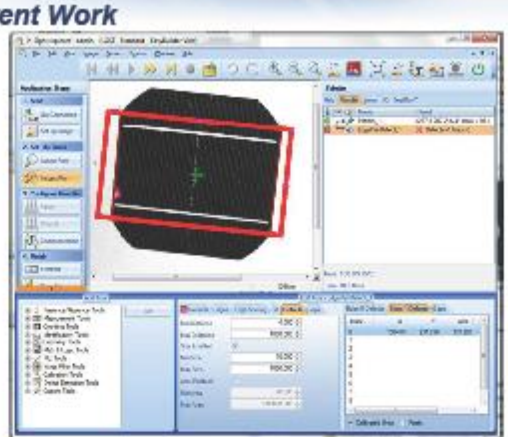
Current Work



Sage Thibodeau   Insight-Explorer Easybuilder   https://www.cognex.com

Idaho National Laboratory

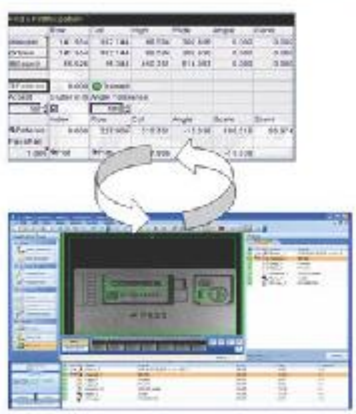
Current Work



Sage Thibodeau Insight-Explorer Easybuilder https://www.cognex.com

Idaho National Laboratory

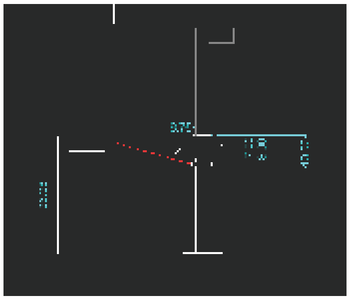
Current Work

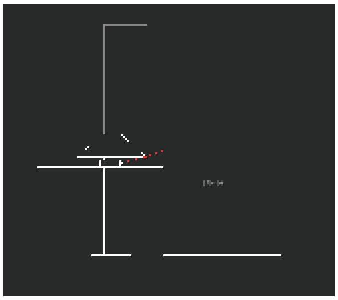


Sage Thibodeau Insight Explorer Spreadsheet https://www.cognex.com

Future Work

- Continue machine vision programming
- Build motion sensor bracket and cover





Sage Thibodeau

Future Work

- Integrate machine vision and sensors with UR-5
- Create final program

Sage Thibodeau


Questions?

Sample Preparation Laboratory Senior Design Project

IDAHO STATE UNIVERSITY
ME 4496

April 20, 2016

Cody Race
Larinda Nichols
Jerron Berrett
Sage Thibodeau

Mentor: Kevin Croft – Sr. Advisory Engineering, INL

www.inl.gov

Who We Are – TEAM SPLT

- **Cody Race** – Senior, ME, NE
  - Team Leader
  - Vision System
- **Larinda Nichols** – Senior, ME, NE
  - Hardware
  - Radiation Effects
- **Jerron Berrett** – Senior, ME
  - Kinematics
- **Sage Thibodeau** – Senior, ME
  - Electronics
  - Programming

SPLT Teleoperations

Cody Race

Idaho National Laboratory

Background

- Idaho National Laboratory (INL) at Materials and Fuels Complex (MFC)
  - Building new facility Sample Preparation Laboratory (SPL)
- Provide radioactive sample preparation, micro- and nano- examination

www.inl.gov

Larinda Nichols

Idaho National Laboratory

Senior Design Project

- PROBLEM STATEMENT:

  INL needs the capability to load and unload radioactive samples from a transport system to examination equipment remotely.

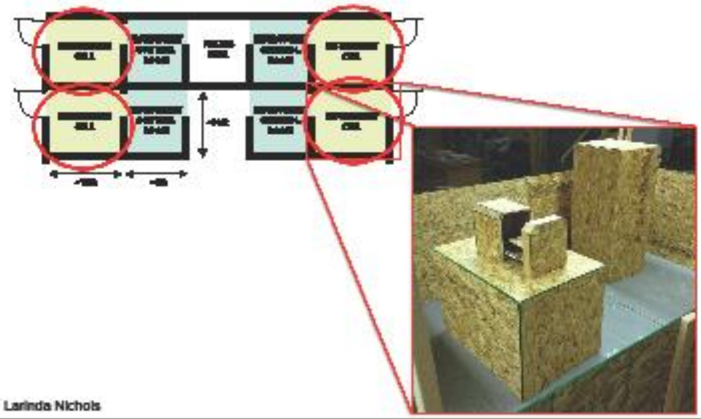
- OBJECTIVE:

  Investigate the integration of kinematics, electronics, material sciences and radiation physics for the design of a system for use in a nuclear hot cell environment.

Larinda Nichols

2

Conceptual Design – Instrumentation Cell



Larinda Nichols

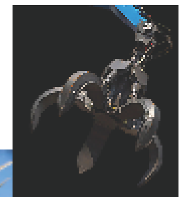
Constraints & Specifications

- **ACCURACY**
  - System must place sample within a 0.01 inch radius from the desired location
- **REPEATABILITY**
  - System must meet the accuracy specification 99.99% of the time
- **RADIOLOGICAL ENVIRONMENT**
  - Equipment must be able to withstand up to one Curie Cobalt 60 exposure
- **RADIOLOGICAL SAFETY**
  - Personnel shall not be physically present in the cell during operation
- **OVERALL COST OF PROJECT**
  - Must meet a budget of $50,000
- **COMPLEXITY**
  - Project to be completed within 9 months (May 2016)

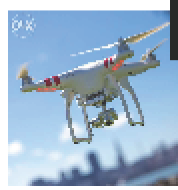
Jerron Berrett

Preliminary Ideas

1. MASTER SLAVE MANIPULATOR
2. ARMORED SUIT
3. ROBOTIC ARM
4. ROBOTIC ROVER
5. CHUTE/CONVEYOR BELT
6. CRANE CLAW
7. HELI-QUAD COPTER



http://scrappyandbolton.co.uk/



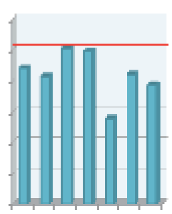
http://www.all-things-photography.com/

Jerron Berrett

Decision Matrix

Specification	Weight	Concept 1	2	3	4	5	6	7
Removal/return of sample from pneumatic transfer system.	5	5	5	5	5	0	5	3
Removal/return to rabbit	5	4	5	5	5	0	3	3
Removal/return to instruments	5	4	5	5	5	0	1	1
Vision (optics/window)	3	2	5	3	3	3	3	3
Ability to react to dropped sample	5	5	5	3	5	0	5	5
Accuracy	5	5	5	5	1	3	5	3
Repeatability	5	3	5	5	1	0	1	0
Multi-personnel operation (lefty/righty)	4	2	5	5	5	5	5	5
A total dose of 1 x 10^6 Rad shall be the basis for equipment radiological design (1 Ci Co 60)	5	5	0	5	5	5	5	5
No sharp edges	3	5	5	5	5	5	4	5
Safety	3	3	1	5	5	4	2	2
10-year life cycle	3	5	0	5	5	5	5	1
Easy to upgrade/ modular	3	0	2	5	5	0	0	5
Cell size (10.3' X 8')	4	3	5	4	5	3	5	5
Lifetime cost	2	1	4	2	2	5	3	5
Complexity	2	5	0	2	2	5	4	0
Total		217	212	258	247	143	216	198

Master Slave Manipulator	1
Armored Suit	2
Robotic Arm	3
UGV	4
Chute/Conveyor Belt	5
Crane/ Claw	6
Heli-Quad Copter	7



Jerron Berrett

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Idaho National Laboratory

Individual Responsibilities

Tasks	Dates
Group construction of mock-up	08/24/2015 – 05/04/2016
Degrees of Freedom	01/11/2016 – 01/18/2016
Robotic Choice	01/18/2016 – 01/25/2016
Articulation Tools	04/10/2016 – 04/27/2016

Jerron Berrett

Idaho National Laboratory

Degrees of Freedom

- Degrees of freedom (D.O.F.) of a robotic arm
  - Number of single-axis rotational joints in the arm
- Determined 5 D.O.F were adequate based on kinematic analysis

http://www.industrialvision.co.uk/

Jerron Berrett

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Comparison of the two robotic arms

UR-5

- Reach of 33.5 inches
- Cost $25,600
- Smaller but capable of completing the task
- Smaller radius for sample to go if dropped
- Payload of 11 pounds

UR-10

- Reach of 51.2 inches
- Cost $40,000
- Has larger reach and capable of completing the task
- Larger radius for sample to go if dropped
- Payload of 22 pounds

Jerron Berrett

Robotic arm choice

- We chose the UR-5 Robotic Arm
- Chosen based on a smaller radius to limit the off-normal, dropped sample situation
- Cheaper than the UR-10

http://www.universal-robots.com/

Jerron Berrett

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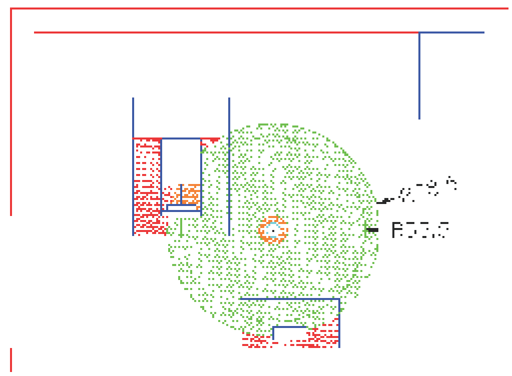
Robotic Arm Reach



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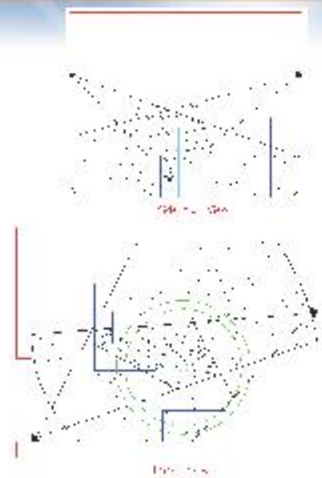
Individual Responsibilities

Tasks	Dates
Group construction of mock-up	08/24/2015 – 05/04/2016
Radiation effects on the vision systems	03/12/2016 – 04/01/2016
Layout of room cameras	03/25/2016 – 04/07/2016
2-D vs. 3-D comparison	04/01/2016 – 04/27/2016
Stereo Vision system	04/13/2016 – 04/27/2016

Cody Race

Room Cameras

- Operation
  - Viewing of process
  - Viewing aid for off normal situations
- Equipment Used
  - 2 Rvision SEE HP
    - Advantages:
      - Pan Tilt
      - 36x Optical Zoom
      - Auto Focus



Cody Race

Machine Vision

- Operation
  - Used to assist in autonomous mode
  - Used for off normal situations
- Equipment Used
  - Cognex In-Sight Micro 1100
    - Advantages:
      - Programmable
      - Recognition of sample orientation
      - Relates information to robotic arm

Cody Race

Stereo Vision

- Operation
  - Provide realistic viewing (3-D w/o the glasses)
  - Use in tele-operations done by operator
  - Redundancy in case autonomous/ Machine Vision failure
- Equipment Used
  - 2 Elmo cameras
  - Dimension Technologies Inc. 2018XLQ Viewing Screen
  - Wildshot 100 Pan Tilt Unit

Cody Race

Individual Responsibilities

Tasks	Dates
Group construction of mock-up	08/24/2015 – 05/04/2016
Research radiation effects on hardware and materials	08/24/2015 – 12/18/2016
Radiation calculations for cell	01/25/2016 – 03/17/2016
System enclosure concepts	01/25/2016 – 04/28/2016
Transfer carriers	03/08/2016 – 04/11/2016

Larinda Nichols

Radiation Considerations

- Samples entering the cell are non-fuel
- Conservative calculations based on
  1 Curie of Cobalt-60
- Approximately 4.5 MeV
- Ionizing radiation
- Does not activate materials

at low energies (under 10 MeV)

Larinda Nichols

* Image above from www.SpectrumTechniques.com

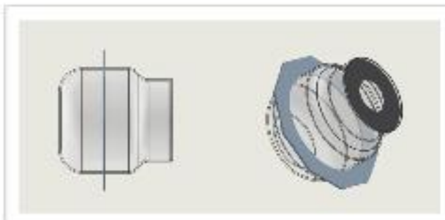
Radiation Considerations

- Metals are unaffected
- Negligible effects on acrylic after decades of exposure
- Wiring and electrical components more susceptible to damage
- Point source calculation
  - Considering a constant exposure to 1 Curie Co-60
  - Distance of approximately 1 foot from source
  - 20 years before any noticeable degradation
- Off-the-shelf commercial wiring
  - Typically unaffected up to a total dose of 1MGy

Larinda Nichols

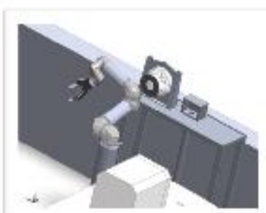
Enclosure Concepts

- Concept 1 – Small Enclosure
- Enclosure "glove" to keep sample contained during transfer from table to instrument, eliminating the need for complete enclosure of entire system.



Larinda Nichols

Enclosure Concepts



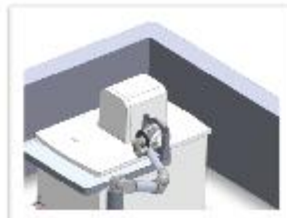
Small enclosure is mounted on the table where sample enters the room.

After sample is retrieved by the robot, the gripper is inserted into the small enclosure.

Larinda Nichols

Enclosure Concepts

Robot lifts to remove enclosure from mount. Enclosure is held on to the robot arm using a thick rubber seal.



Robot transfers sample inside the small enclosure to the instrument table and docks into a second mounting station.

Larinda Nichols

Enclosure Concepts

- Concepts 2 & 3 – Partial to Full Enclosure
- Various configurations of plexiglass can be used with or without the tray to ensure sample remains within the reach of the robot at all times.

Partial Enclosure

Full Enclosure

Larinda Nichols

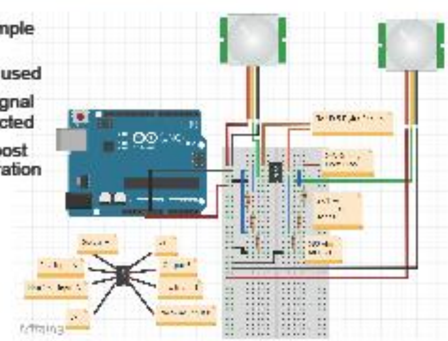
Individual Responsibilities

Tasks	Dates
Make motion sensors compatible with UR5	02/14/2016 – 03/21/2016
Incorporate machine vision into programming	03/15/2016 – 04/08/2016
Develop pseudo code	04/01/2016 – 04/15/2016
Create final program	04/15/2016 – 05/06/2016

Sage Thibodeau

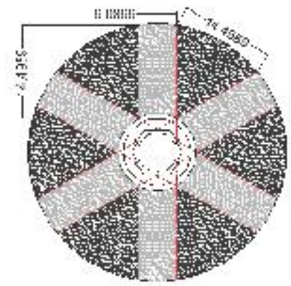
Sensors

- Need to detect if sample is dropped
- PIR motion sensors used
- Sends digital high signal when motion is detected
- Op-amps used to boost high signal for integration with the robot



Sage Thibodeau

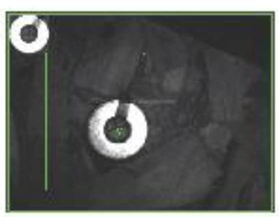
Sensors



Sage Thibodeau

Machine Vision

- Machine Vision consists of a programmable camera
- Can be programmed to recognize patterns
- Used to determine orientation of containers and sample



Sage Thibodeau

Programming

- Universal Robot uses PolyScope to program
- All programming done on Teach Pendant
- Waypoints can be set using three different methods
  - Physically moving UR5
  - Using the Teach Pendant
  - Pose command
- Can be programmed to send or receive digital and analog signals
- TCP/IP connection used to communicate with machine vision

Sage Thibodeau

Programming

- Machine Vision uses EasyBuilder or Spreasheet
- EasyBuilder
  - Quick and easy method of programming
  - No programming or spreadsheets needed
- Spreadsheet
  - Set up like an Excel spreadsheet
  - Allows for full control of vision system
  - Provides access to complex logic statements
- When triggered, machine vision sends angle data to robot

Sage Thibodeau

Budget

Item	Total Cost	
Robot / Gripper	$	31,523.00
Mock- Up Material	$	1,004.60
Robot Stand	$	116.82
Vision Systems	$	9,471.57
Mentor Travel	$	1,200.00
Total Spent	$	52,412.34
Total Material Budget	$	55,000.00
Remaining Budget	$	2,587.66

Sage Thibodeau

Robot in Motion!

Sage Thibodeau

Design Completion

- ☑ **ACCURACY**
  - [illegible] desired location
- ☑ **REPEATABILITY**
  - [illegible] manufacturer)
- ☑ **RADIOLOGICAL ENVIRONMENT**
  - [illegible] cobalt 60 exposure
- ☑ **RADIOLOGICAL SAFETY**
  - [illegible]
- ☐ **OVERALL COST OF PROJECT**
  - [illegible] 0,000
- ☑ **COMPLEXITY**
  - [illegible] 9 months (May 2016)

Sage Thibodeau

Questions?

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