Small Business Innovation Research Program Phase I NSF Proposal
Topic: Electronic Hardware, Robotics and Wireless Technologies (EW) Subtopic: Robotics and Human Assistive Technologies (RH): RH2. Robotic Applications.
Project Name: Brief (Biological robotic imaging experimentation framework)
Joseph Crandall - Words: 3478

BRIEF Project Summary

Box 1: Overview, Key Words, and Subtopic Name:
The topic is Electronic Hardware, Robotics and Wireless Technologies (EW) and the subtopic is Robotics and Human Assistive Technologies (RH): RH2. Robotic Applications. The acronym for the project BRIEF stands for Biological Robotic Imaging Experimentation Framework. Joseph Crandall is conducting Schuck Robotic manipulation and computer vision research in order to develop a robotic system that can image and manipulate a plant. This point cloud based imaging research has the potential to generate savings for agricultural products that require human labor and dexterity to harvest. The system will also provide point cloud over time data for botanists working to quantitatively measure plant development. The following resources are being used for the robotic component of the project and can be treated as key words, Schunk ROS Package (http://wiki.ros.org/schunk_canopen_driver), Peak-systems Linux (http://www.peak-system.com/PCAN-USB.199.0.html?L=1), ROS Kinetic Kame (http://wiki.ros.org/kinetic), ROS Control (http://wiki.ros.org/ros_control), ROS Gazebo Integration (http://gazebosim.org/tutorials?tut=ros_overview), and Yale OpenHand Project (https://www.eng.yale.edu/grablab/openhand/).

Box 2: Intellectual Merit

The Robotics component of the research encompasses three main technical challenges, gaining a working understanding of a prebuilt ROS package for the Schunk LWA 4P in order to drive the arm, a working understanding of the Gazebo robotic simulator in order to run a simulation of the Schunk LWA 4p, and using sensory point cloud data from an Xbox Kinect inside of a simulation world in order to give the robot arm sensory information. Once functional, the arm will be able to perceive, through the point cloud, complex geometric structures and be able to interact with them via a point cloud to mesh conversion software.

This project will require the developer to become familiar with all of these packages mentioned in the overview section in order to integrate them for the Schuck Robotic System. Many of the basic features needed for this project have already been implemented and refined by the robotic operating system open source community. To use one's development time wisely it is beneficial to become the well versed in what has previously been done to avoid duplication of code.

This research should be viewed as both a learning experience and a development process. The student will gain a better understanding of ROS and its community in order to drive the robotic system. The student will also implement software to interpret the point cloud data to make it usable for the robot.

Box 3: Broader/Commercial Impact:

This project will make Robotic tools for interacting with biological processes more useful to biological researchers and more commercially viable across many agricultural sectors. Although automation in machining and manufacturing has been well developed, the same principles for these controlled closed environments do not always lend themselves to dynamic ones. However, many dynamic biological environments could be automated with this technology. One example is for fruit harvesting and indoor/vertical farming. The orientation of the plant sites can be controlled, and with this system a point cloud to mesh interpretation of the plant would allow the robotic arm to grasp the biological structure and harvest it.

BRIEF Project Description

Elevator Pitch

The Customer

The natural world is chaotic and continuous. Researchers trying to find the patterns in its many intricacies are faced with a gauntlet of challenges. Greater still are the challenges faced by businesses whose economic viability depends on natural processes that can be disrupted, through no fault of the produced, by natural cataclysms. In such a world, it is helpful to implement some form of mechanization in order to both produce quantitative biological studies and reap greater returns when natural conditions are favorable for industrial agriculturalist.

The scientific botanist or biologist would benefit from using a plant imaging and manipulation platform because it would provide the scientist with systematic and reproducible point cloud and mesh data of the the plant under investigation over an extended duration of time. Certain plants could be monitored from origin to death with minute to minute precision. This data could then be used to create three dimensional movies of the plant development. The level of accuracy provided by the Xbox Kinect point cloud camera is what distinguishes our platform from any manual data gathering alternative. Even the most diligent and observant single graduate student does not have the stamina to observe and record plant development every minute for a three to six month period. A team of graduate students could be employed to do this, but this would take time away from their study and analysis of the data. When comparing opportunity cost of time spent for these graduate students, and astute PI would see the value of our plant imaging and manipulation platform data acquisition process.

The industrial agriculturalist would have the ability to use our prototype system to explore harvesting techniques in traditional and indoor farming for monitoring and harvesting of delicate produce. The plant imaging and manipulation system is **not mobile** so its manipulation range is limited to the area of the circular stand on which it is mounted. A potted fruit or vegetable plant could be placed on table. The plant growth would be monitored and when the fruit coloration and size met a predetermined characterization, perhaps based on a continuously refined machine learning algorithm, the Schuck arm and gripped would be manipulated to grasp the fruit, harvest it, and place it in a desired location within the range of the arm.

The Value proposition

Our plant imaging and manipulation system will save the research or industrialist man hours that would be monotonous, and in some cases impractical for a single human to conduct. When deciding whether to purchase our system, the buyer would only have to ask themselves what their current labor costs are, factor in elongated costs such as pensions or healthcare for the industrialists, or opportunity cost for the the PI's graduate student's whose time would be better spent analysing the now autonomously acquired data. If the buyer believes that this cost is greater than the cost of our system, the company think that an intelligent consumer would decide to purchase the plant imaging and manipulation system.

The Innovation

Our innovation is **not** the development of a new technology, rather the pairing of two separate fields within computer science in order to develop and system that can succeed in imaging and harvesting the polysemous low hanging fruit. The company are going to utilize a computer vision algorithm the translates point clouds to meshes. The company send this data to a Gazebo simulation. The simulation will give a frame of reference for the robot and the plant. The company will then calculate the prefered route for the Schunk arm to move. These movement commands will be sent as instructions and implemented via the ROS operating systems. This pairing of physical manipulation, simulation, point cloud sensory data, and mesh conversion is what makes our product unique. Although autonomous harvesting of grains has been available since the invention of the combine harvester, there is a lack of options for autonomous harvesting of delicates items such as produce, which is primarily harvested by hand. The company hope to add another options to the researcher and or farmer's toolbox if they see fit to buy our product.

Commercial Opportunity

Industrialized agriculture plays a large role in our lives. However a large amount of the machinery that it is used in the harvesting of agricultural products is targeted at harvesting grains. Modern Standalone Combines have been in existence since the 1950's. Combines harvest crops such as corn, grain, and soybeans. They are able to separate the plant from the seed through a process called thrashing. The threshing process has been refined over the years and involves vibration and spinning. This process works very well for sturdy crops. However, implementing the same process for strawberries would be disastrous. Strawberries present two challenges: they are delicate and can be damaged when exposed to too much force. Secondly, the entire strawberry plant develops over a period of years, if you harvest the entire plant to remove one season of strawberries you will destroy the plant in the process and will have to wait multiple years for another set of plants to mature. With these constraints one must approach the problem from a different direction.

If our company uses the strawberry market as a case study for how this technology can be applied, it is important to consider that current state of the strawberry market. A 2015 Wall street Journal report[1] noted a trend. Between 2005 and 2015 the number of illegal immigrants of mexican origin detained by United States border patrol dropped from over 900,000 per year to under 300,000 per year. During the period from 2010 to 2015 wages per hour increased by 5% to $11.33 per hour. The shortage of workers, combined with the increase in pay, demonstrates the shortage of supply for unskilled farm hands for strawberry harvesting.

A common metric for the strawberry industry is the cost paid to a worker to harvest a flat, approximately 288 strawberries. The average price paid to harvest a flat is $1.50. Robotic systems along with the software developers and contracts to support them can cost hundreds of thousands of dollars. This requires the robotic systems to be able to harvest tens of millions of strawberries before the robotic systems can pay for themselves. So can a robotic system make economic sense in the strawberry industry? With some quick back of the napkin calculations,

[1] http://www.wsj.com/articles/robots-step-into-new-planting-harvesting-roles-1429781404

one can discover how many acres of strawberries a farmer should grow before an industrial robotic harvesting system starts to make economic sense.[2]

With 48 inch row spacing and 12 inch spacing between plants in each row a farmer can expect to raise about 10,890 strawberry plants per acre. If each plant produce on average 150 to 400 grams of strawberries in a growing season and one takes 275 grams for our calculation with a medium size strawberry weighing 12 grams, then the results in approximately 22 strawberries per plant per year. Which equates to approximately 239,580 strawberries per acre per year.

The robotic arm for a Schunk Robot costs approximately $50,000 and the robotic three finger grabber for the Schunk robot costs approximately $60,000. If our company provides software and support for five years at a service cost of 10,000 a year, our Hardware as a service product costs the farmer approximately $160,000 over the course of five years.

In this case study, the cost of paying a hired hand to pick the strawberries is set at $1.50 per flat and assumes the that amount of strawberries per flat is approximately 300 strawberries. At this rate, the farmer is paying on average $0.005 per strawberry harvested. To compete, our machine must harvest approximately 32,000,000 strawberries over the course of five years (or 6,400,000 strawberries per year). When incorporating the number of plants per acre and strawberries per plant, our company models that a farmer should have over 26.7 acres of strawberry plants per year to justify using our Hardware as a Service product.

With these calculations in mind our customer is the industrial strawberry farmer who has approximately thirty or more acres of annual strawberry growth and is looking to transition away from manual harvesting to automated harvesting. In our initial case study, the company noted what conditions are necessary to justify purchasing our machine as the well as our support services. However, this may not be the payment model that our customer elects to select. Therefore, the company proposes offering a range of payment models to chose from. The company's first option allows our customer to purchase the hardware along with our software and support contract. The second option is for the customer to simply subscribe to the support contract for a fixed period with the company providing the hardware on demand. Finally the company offers our customers with a third option of a single-use payment model where our services can be contracted for one off harvest sessions. This flexibility allows the customer to utilize a payment method that fits their needs. These three options are summarized as follows, Hardware Support, Hardware as a Service, and One Click.

Our company is not the only company competing to provide automated harvesting for strawberry farmers. Our primary competitor is the spanish company Agrobot[3] . Agrobot provides a mobile, multi-arm, conveyor belt fed strawberry picker. This product has been under development since 2009 and provides all of the services our product hopes to provide and more. However, since our product is being developed in an academic environment, our company have access to problems that the Agrobot does not. Our company can provide our system to biological researchers who are looking to quantitatively measure plant development over time. Our system can generate a point cloud mapping of plant growth over an extended period of time with the ability to manipulate the sample as it is growing. The flexibility of our

[2] http://strawberryplants.org/2010/10/strawberry-plants-per-acre/
[3] http://www.agrobot.es

system means that it is not optimized for either industrial agriculture or for scientific point cloud mapping, however it can be used for both. This flexibility is what differentiates us from the competition.

In robotics and automation, the competitive landscape is always changing. This is great for the consumer; it means that the company needs to keep updating our systems while maintaining the features that initially interested our customers. As the demand for unskilled farm labor continues to rise, it is likely that more automated systems will be developed for other delicate produce products that are difficult to harvest. This coupled with advances in computer vision and machine learning allow for more robust systems that are able to manipulate a wider array of items for lower costs. Luckily, there are not other products that already have the high degrees of freedom and flexibility that the company provides while targeting the two small segments that have been addressed. However, in our globally competitive environment, there is no way of telling when another startup will come out of hiding and be in direct competition with our company. All the company can do is continue to improve our product.

The risks the company is taking are capital intensive and therefore should not be taken lightly. In order to offer a product in which the company provide our users with support for our software as well as robotics components on demand contributes to a high degree of risk for the company. The company must purchase and maintain hardware that at a minimum has costs in the hundreds of thousands of dollars. The company must raise funds to make these purchase prior to taking in revenue from our services. This puts the company in a detrimental position if it acquires the initial money through a loan or through the loss of equity through investment. If the company fails, loans will still have to be repaid and the entrepreneurs images will have been damaged.

If our venture is successful and the strawberry case study is in the correct order of magnitude, the company can expect to make upwards of $50,000 per five year contract to strawberry farms of upwards of 30 acres of strawberries or greater. The company must investigate further into the different financial projections for the three payment options, Hardware Support, Hardware as a Service, and One Click.

Broader Impact

expanding population for a cost that is affordable to a larger percentage of the population, technology Fresh produce is an important part of a healthy diet. In order to provide this produce to anmust be utilized. If our product can provide a larger percentage of the population with the produce they want at a cost they can afford then the company has succeeded. If the company is able to grow our business and continue to develop our technology the company can continue to push down the cost per unit of harvested strawberries through economies of scale.

Unfortunately fresh fruit can be priced and perceived as a luxury item. If our company wants to have a broader social impact our technology needs to be good enough to not only be an economically viable alternative to hired hand based harvesting, but able to lower the cost per unit of strawberries harvested. If our automated harvesting systems are used widely enough it may give enough farms a competitive advantage so as to change the economics of the strawberry industry. In this scenario a paradigm shift would occur resulting in a percent decrease in the cost per unit of strawberry harvested and the destruction of the hired hand strawberry workforce. Automation is making our world more productive and raising GDP, it is also destroying jobs. Automation is a global trend and is making its way into industrial agriculture into sub sectors that previously could not be automated. This shift has both positive and and negative repercussions. As unskilled laborers are displaced they have to reevaluate how to retrain themselves or face chronic unemployment. This is not an enviable situation to be in and is unfortunately the reality for many individuals. However, strawberry farmers who embraces new automation technologies will be more competitive than those who do not. For the consumer, this product will help to decrease the cost of strawberries and hopefully make strawberries an accessible product to a greater percentage of the population.

Environmental process that are manipulated by automated, repetitive systems often respond in unanticipated ways. Entropy is real. Moving one bolt from one conveyor belt to another conveyor belt is very different from removing a strawberry from the vine and placing it in a clamshell container. Successful species adapt over time and it is this adaptation that must be accounted for. Overtime the automated process may deprive the plants of some nutrient or dampen or amplify some chaotic forces that helps in plant development. Either way, it is difficult to predict these adverse effects that new technology may create. The company will have to deal with these problem when they presents themselves. In terms of health and safety is is important that our system does not introduce any toxic components into the food the robot harvests. When the company is prepared to certify our first prototype, one of the steps the company will take is to present the system to the proper government agencies so as to certify that the product is safe.

Our product may create a backlash from the organized strawberry harvesting workforce fearing the loss of their jobs. However if the technology is good enough, the economics of automation will inevitably lead to hired hand job loss. As with any powerful robotic system, there is the possibility of injury due to poor design, operator error, or malicious intent. Our goal is to minimize the first, train our users to avoid the second, and make it difficult for bad actors to carry out the third. The company's product will need regulatory approval for both its needed level of sanitation as well as certification for operator use as well as age limits for operator use.

Our technology is another example of the automation of unskilled labor. The common solution to this problem is the retraining of unskilled laborers in new fields of work. This solution is weak and does not address the greater problem of an overall decrease in the amount employee's needed to maintain or accelerate growth. This is a not a problem that our company can hope to solve, but perhaps we can help. If done correctly, the company's robotic harvesting system will results in healthy food that is less expensive to harvest. This success comes at the cost of job loss. In order to offset this job loss it is possible to create an apprenticeship program where hired hands who have lost their jobs are able to shadow members of the company and learn how we develop our machines. It is difficult to know how well this will scale and it is certain that the company will not be able to provide training for all the jobs the company displaces with our machines, however it does provide a route for some motivated individuals to learn from the individuals who displace them.

Brief (Biological Robotic Imaging Experimentation Framework)

The company’s automated strawberry harvesting product will contributing to a more competitive world, so the next time you are up late stressed over an impending deadline that requires unprecedented levels of innovation, you can enjoy a ruby red strawberry for reduced cost and think about how far we have come.

Technical Discussion and R&D Plan

BRIEF Purpose and Objective

Motivation

Joseph Crandall and Karl Prisner are collaborating on our join senior design project with the Simha Lab to deliver a **Biological Robotic Imaging Experimentation Framework (BRIEF)**. In this case framework means a physical imaging stage and robotic arm accompanied by point cloud interpretation software and ROS driven robotics. The purpose of BRIEF is to create biological sample development pointcloud movies while manipulating the samples as needed. Our finished project will include a robotic arm, imaging stage, rotating point cloud sensor, and a robotic gripper. Our robotic systems will be controlled through the Robotic Operating System (ROS). Our system will be simulated in a Gazebo simulation world. Our framework will provide a researcher with quantitative point cloud data of the changing geometry of a biological process over an extended duration of time. By working with the Simha Lab and the GW Biological Sciences Department we have identified that the department has a need for a device with these capabilities to conduct plant development research.

Users

A researcher could use our product to conduct an experiment where a plant's development over time could be monitored and then played back through a point cloud film where the geometric changes could be viewed from all angles and data science techniques could be used in the analysis. Currently we do not have a user interface planned since the control of the robot is run through a linux command line interface by issuing ROS commands. Once the development has reached a point where a user can issue a command to the robot and to the simulator and they behave identically we will look for ways to implement a drag and drop user friendly interface. At this time no work has gone into the user interface.

Use cases

A typical use case involves a biological sample, BRIEF, and a researcher. We will strive to minimize the amount of BREIF system knowledge the researcher has to have to operate the system. The researchers priority is to acquire relevant data, anything that distracts from this will be abstracted from the researcher. The end goal is to have a washing machine experience. Place your sample, designate the timescale of the experiment and what you would like to monitor and then begin. Joseph Crandall and Karl Prisner are a ways from this at the moment.

Function and Non-Functional Requirements for Components

Overview of Components

Due to the scale of this project, Joseph Crandall and Karl Prisner have split the workload of the project. Through a divide and conquer approach we may better tackle components that will eventually be brought together in the final system. Joseph Crandall will be responsible for understanding how the ROS operating system works with the Schunk Robotic Arm. Mr. Crandall will also port the python code running the open source yale grabber into a ROS package so that the grabber can be used in unison with the Schunk Robotic arm. Behind the robotic operating system that will drive the robots will be a series of launch files that issue the joint movement commands. As the team becomes more experienced at writing launch files will will start to work on improving the usability of the system so that novices can move the robot without having to understand the details of ROS.

Mr. Crandall is also working on the Gazebo simulator being used for the project. There are multiple robotic components for the project including the arm, the grabber, and Karl Prisner's Imaging arm. It is important to understand how all the components work in unison, primarily to avoid collisions. The Gazebo simulation will allow our team to learn how to execute commands in both a simulated environment as well as the physical one. From an inverse kinematics perspective this is necessary because if the timing of actuators are not properly tested there is a possibility that the robotic arm and grabber will collide with the imaging arm. Additionally the ability to import point cloud data into the simulated world is one way that we may be able to interpret the point cloud data in order to issue movement commands to the robotic arm and grabber to manipulate the sample.

Schunk LWA 4P driven by schunk_canopen_driver through ROS

The Schunk Light Weight arm is where most of Mr. Crandall's work had been dedicated. A majority of the allotted project time has been spent learning about ROS (the Robotic Operating System) in order to properly use the package schunk_canopen_driver in order to send commands to the robot. The initial functional requirements of this system focus on having a full understanding of what is already written within the schunk_canopen_driver and the ability to execute all possible user directed commands. Once this is complete, the second set of functional requirements will focus on giving the arm point cloud data of the object that has been imaged. The driver for the arm will then have to decided how to send a series of movement commands to the arm to interact with the object represented by the point cloud.

Yale Open Hard driven by python script

The first functional requirement for Yale Open hand is to be able to run the python script to properly open and close the hand. The second functional requirement is to create a ros package for the yale open hand so that it can be driven within a ROS environment. The third functional requirement is to incorporate the ROS open hand package with the schunk_canopen_driver package as well as physically attach the open hand to the robotic arm. The goal is to be able to calculate inverse kinematics on the full arm grabber system so that the arm and gripper can be driven as one.

Gazebo Simulation

The Gazebo simulation world allows for the testing of robotic components, and the integration of multiple components. The simulation acts a test bed where launch files can be executed without fear of damaging the robot due to improper movement of joints that may cause the robot to collide with itself or with another object in the world. The simulation also proviudes a visualization for all of the components of the project.

Imaging Stage, Xbox Kinect, & Imaging Arm

These components are be developed by Mr. Preisner. Once the imaging stage and arm are working independently we will combined the stage, arm, gripper, and imaging arm in the Gazebo world simulation. At this point we will mount arm and gripper at the center of the imaging stage where it will be able to reach any location on the stage. To run the full system we will develope a ROS package to incorporate the movement of the imaging arm with the movement of the schunk arm and yale gripper to be able to calculate inverse kinematics on the whole system.

Classes and interfaces for implementation of components

Packages

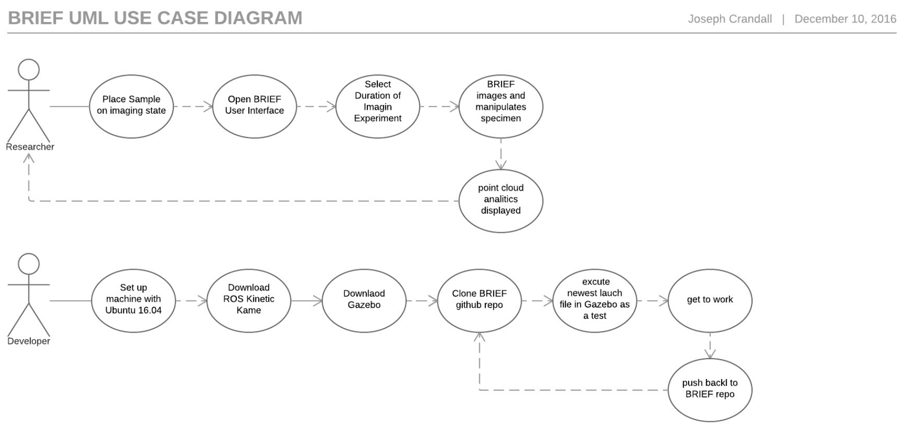
At this state in the project is is better to think in terms of package because this seems to be the method in which ROS designates a specific set of functions. We already have the schunk_canopen_driver package. This package will need to be extended in order to add a form of point cloud interpretation and interaction. We will need to write a new ros package for the Yale Open Hand which is currently manipulated through a series of python scripts. We will also have to create a model of the Yale gripper for the Gazebo simulation.

Interfaces

Currently the only way to interact with the ROS code or the Gazebo simulation is though an Ubuntu Linux command line interface. As the project matures it will be important to identify a more user frields method of running experiments with the system. At this time however this is not a priority since we do not fully understand how all the robotic systems, command files, and simulation will interact. Once we have a better idea about how these systems interact we will be able to think about an interface that provide the use with the content and control they want without having to deal with all the details associated with ROS.

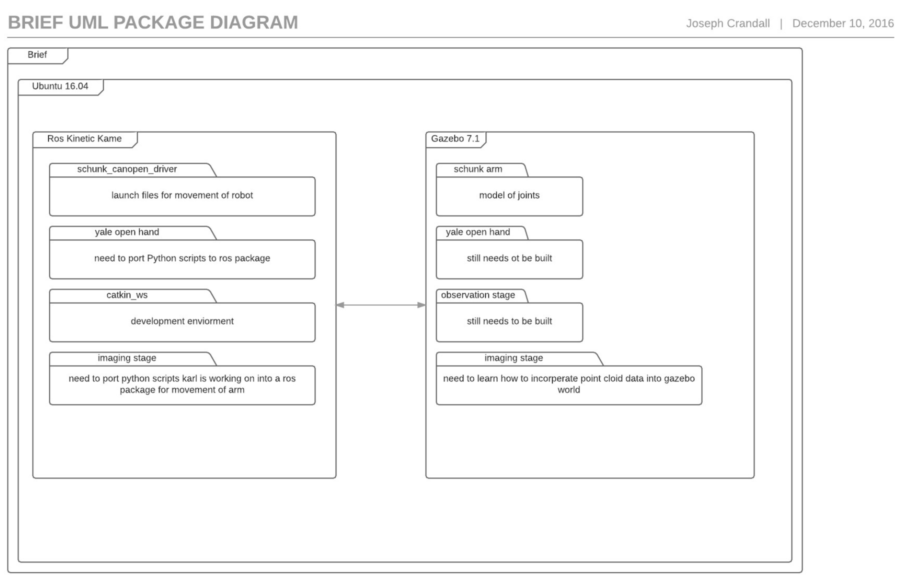
5.2 Context: Design Viewpoint

UML use case diagram



5.3 Composition: Design Viewpoint

Logical: UML package diagram,



5.4 Logical: Design Viewpoint

UML class diagram (not complete, more development needed first)

Software & Hardware Development Timeline

Dec 2016 - January 2016

- Complete Gazebo model of the Schunk LWA-4P and issue launch files to manipulate the Gazebo simulation
- synchronize commands and manipulation of gazebo simulation with physical Schunk LWA-4P

February 2016

- Operate Yale Open Hand with python scripts
- Create ROS package for ROS based Open Hand gripper
- Create Gazebo simulation for ROS based Open Hand gripper

March 2016

- Integrate Schunk LLA-4p and Yale Open Hand gripper in a single ROS package and create a Gazebo world of the combined system.

April 2016

- Integrate arm and hand with Mr. Prisner's imaging stage, imaging arm, and xbox kinect
- Create new ROS package and Gazebo world simulation, focusing on incorporating the point cloud data.

May 2016

- Start work on user interface for the system.

Comments

This is a very ambitious schedule and from past experience working with ROS and Gazebo, steep learning curves can present themselves as progress is made. Each one of these needs to be internalized before moving forward. Dr. Simha has stated that this research project will continue on after Joseph Crandall and Karl Prisner have graduated so it is the teams goal to make the work transparent and easy to pick up for the next students who join the research group. We have put a large amount of work into understanding the foundational material for ROS as well as fabricating parts for the imaging stage.