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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 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 goal of the project is to develop a system that can generate a point cloud model of a biological sample. At the conclusion of this research, botanists will be able to measure plant development by analyzing point cloud data.

The project will introduce an affordable means of quantitatively measuring plant samples via point cloud data collected from a 3D scanning device. The device is a 4’ diameter circular table with a motorized camera arm that can circumnavigate the table to produce a 360-degree model of the table.

Keywords: NP-complete (https://xlinux.nist.gov/dads/HTML/npcomplete.html).
Point cloud: a set of data points in some coordinate system.

Box 2: Intellectual Merit:

When constructing hardware, it is necessary to find a cheap and effective solution to finding and correcting the drift in motors. Additionally, the arm structure and motors must be sturdy enough to hold a three-pound camera at the end of a 5’ arm without wobbling during motion.When working with robotics hardware and software, multiple interfaces and languages need to be synced together effectively. The team will develop an algorithm for the inverse kinematics of the camera’s arm motion and software to convert point cloud data from a single image capture to a 3D model of the image.

The ultimate goal for this phase of the project is to develop a learning algorithm for scanning an object on the table. After the first scan, the algorithm will use the point cloud data of the image to find an optimal selection of camera locations that will scan the entire object. Taking excessive pictures will result in having too much data for the algorithm to analyze. Optimizing the scanning camera locations will diminish execution time and eliminate redundant data. This optimization algorithm is NP-Complete and will require a great deal of effort to develop.

Box 3: Broader/Commercial Impact:

This project will provide biology and botanist researchers a new tool for precisely measuring slowly changing objects (plants) over vast periods of time. Introducing this 3D Scanner to research groups will eliminate countless man hours. The liberated time can then be allocated towards analyzing the data instead of gathering it. Furthermore, this 3D scanner is not designed for creating a large quantity of scans at high frequency. Most research groups do not have use for the density of data current 3D scanners generate and can complete their research with a fraction of the data set. Moreover, similar tools for creating large 3D renderings of objects are over budget for most universities and research groups. This 3D Scanner is built with much more affordable hardware that reduces the overall cost of the product.

Project Description

Elevator Pitch (no more than one page)

Botany researchers and produce agriculturalists alike, look no further for the solution to all of your plant-analyzing, produce-harvesting issues! I offer you the single most revolutionary product in all of modern botany: the 3D Scanner. The 3D Scanner provides an affordable and effective way of quantitatively measuring plant development over extended periods of time. The scanned object is converted into point cloud data which can be analyzed, allowing for the impeccable caretaking of produce and other plants. In fact, when the images are strung together, the 3D Scanner reveals a 3D movie that shows how a plant develops. Imagine all of the time the 3D Scanner will liberate from your graduate student or research assistant that can be allocated towards more important tasks than painstakingly measuring a plant with a tape measure over and over again.

When paired with the Schunk Robotic Arm, wishful thinking of automated produce harvesting becomes a reality. As it moves through time and space, the Schunk Robotic Arm interprets the point cloud data that the 3D Scanner provides. In this day and age, automated machines for harvesting grains such as wheat and corn are readily available for purchase. However, there are not any automated machines used for harvesting produce- until now. If you are an industrial agriculturist seeking the single most revolutionary path to the future of produce harvesting, the 3D Scanner paired with the Schunk Robotic Arm is the perfect combination for you.

Currently, the likelihood of finding a 3D time lapse scanner of this size and effectiveness available is little to none. The 3D Scanner is revolutionary, unlatching windows of opportunity and discovery in botany. Its ability to analyze point cloud data of the growth rates of plants will lead to new advances in agricultural and plant technology, eventually revolutionizing the way we view the world around us.

The 3D Scanner is comprised of a four foot diameter metal table with a motorized camera arm that circumnavigates the perimeter of the table to create a 360 degree model of the object on the table. On the tip of the arm rests an Xbox Kinect 2 camera along with an infrared light sensor. The metal arm has several motorized joints that provide the camera with multiple viewing angles. The Kinect 2 camera and all of the motors are controlled using a Raspberry Pi and programed in C++ and Python respectively. The Raspberry Pi is connected to any computer via an ethernet cable where a researcher can control the camera's movements.

No other piece of modern technology has the ability to revolutionize the way our civilization gathers produce information like the 3D Scanner paired with the Schunk Robotic Arm. When this innovation becomes readily available to the agricultural community, it will be able to further the pursuit of a world where all produce is grown and maintained with automated machines.

Commercial Opportunity and Societal Impact (3-4 pages)

Imagine a world where working hours are decreased while wages are simultaneously increased; a world where malnutrition becomes a distant memory as a variety of produce becomes available for mass consumption. This world is nearly at our fingertips thanks to the Automated 3D Scanning with Precise Robotic Manipulation.

The Automated 3D Scanning with Precise Robotic Manipulation, also known as the ASPRM, is embodies innovative technology and high-functioning-yet-comprehensible components offer a unique commercial opportunity for customers on an entire spectrum of experience and interest in an assortment of fields. The ASPRM may be utilized for a variety of functions. These functions include 3D scanning of the most intricate of objects in fields such as forensics, medicine, and education. Additionally, the ASPRM's unique design that which enables the manipulation of objects may be key in the handling of medicinal apparatuses, civil engineering tools, and many other objects in need of handling. ASPRM's versatility indicates that it may have quite the expansive addressable market; however, the ASPRM is specifically designed for the botanical and agricultural market.

In the botanical market, the ASPRM would provide a wide range of solutions for anyone from casual botany enthusiasts to experienced botany researchers. For both levels of experience, the ASPRM helps and individual catalog and monitor the development of plant growth over time. This development analysis is characterized by measuring the volume and temperature of the plant at all possible surface areas accessible by the ASPRM. These possible surface areas are accessed by both the camera and robotic arm operating in a synchronized manner. With this technology to monitor a plant's development, botany researchers and enthusiasts alike will be seemingly-automatically drawn to the ASPRM.

The ASPRM maintains a similar place in the industrial and private agriculturalist markets. In this competitive market, the ASPRM enables agriculturalists to harvest produce automatically, saving hours of hard labor time. This technology does so by scanning any given plant for ripe fruit based on data gathered over time, and, when appropriate to, the ASPRM gathers the fruit ready for consumption. In the industry specifically, it is best to paint an image to fully depict the necessity for the ASPRM. Imagine a conveyor belt full of potted produce plants. With the ASPRM handy, a plant may be deposited into the machine, allowing the advanced camera to scan the plant. Following the scan, data regarding the plant is recorded and, over a series of scans, updated. The ASPRM program then interprets the data and identifies different potential states of the produce including ripe fruit and branches that need pruning. The automated arm of the ASPRM may then pick the fruit and prune the branches as needed. Thus, the ASPRM is directly marketable to the industrial and private agriculturalist markets.

The business economics related to the ASPRM must be sensibly evaluated and followed. Providing the ASPRM on the market requires a carefully planned strategy and steady, levelheaded management. The first step in the strategy to enforce the relevancy of the ASPRM on the market is to first build and develop the product. Following its development, the ASPRM will then be offered to large plant-related companies as a rental to increase interest while encouraging the curiosity regarding the new technology. This teasing interest will result in the skyrocketed consumer demand for the ASPRM, ensuring a promising future for the business. Additionally, as the technology is rented out to companies, the ASPRM business will provide updates, support, and maintenance to clients, while offering services to both install and repair the product. This offering of services will ensure a steady relationship with customers and provide long-term relationships with relevant companies, thus transcending the ASPRM from a new technology to a beloved necessity. Eventually, as the ASPRM becomes available as a sellable product, these services will continue to be offered. Both the consumer demand accumulated following rentals and the sound customer service offered act as market drivers, compelling clients to continue to invest in the ASPRM.

With these market drivers captivating audiences, the ASPRM's customer base will grow exponentially. Given the marketing strategy that which focuses on a brighter, healthier, more nutritional future, the primary customer base for the ASPRM is comprised of botany researchers and agriculturalists those which are either private or industrial. Privately, these customers are chiefly of working age and have at least some interest in or experience with working with produce and other plants. Given that the ASPRM is advanced technology and does require monetary investment, the ideal private customer is of middle- to high-class. Since the ASPRM may be a beneficial factor to those all over the world, the ideal customer does not have a specific residing area. Additionally, the private customer rents the ASPRM for a period of time as needed. Industrially, the ideal customer for the ASPRM is the owner or manager of a well-known corporation in need of a device to analyze plant development and harvest produce. This ideal customer may be from anywhere in the world in need of this technology and rents the machine for an extended period of time before eventually purchasing the machine.

A comfortable business model comprised of several factors is utilized to ensure the success of the business that which surrounds the ASPRM. The first detail of this business model is a design for the operation of the business. A singular Chief Executive Officer who manages and overlooks business operations operates the business of the ASPRM. Lower-ranking staff members who analyze and assess finances, customer relations, and other necessary areas maintain these business operations. This ensures a healthy relationship within the business that which permeates to the success of the business itself. To guarantee the further success of ASPRM in the future, a steady source of revenue has been established. The eventual purchasing of the ASPRM along with the added fees to ensure quality maintenance on the machine act as the business' main source of revenue. Rental fees and contracts as well as the ability to purchase added insurance on the machine during a rental will act as the business' additive source of revenue. Additionally, the product's promise for a brighter future and readily-understood benefits will ensure investors' interests. Over time, the sum of these revenues will overcome the initial payment to produce the machine as demand will exponentially rise as the desire for the ASPRM becomes a necessity. This initial cost, however, is not as high as would be expected with this innovative technology. The robotic arm and grasper as well as the table with the camera arm amount to only $113,000. Added to this, however, is the cost of labor of ASPRM employees as well as the repairs offered by the business to renters. To ensure the financial success of the ASPRM, the company that which leases the machine must use the ASPRM to its potential harvested produce quantity. In this case, all costs for the client are covered, thus ensuring a comfortable relationship with the ASPRM client.

Despite nearly-constant general competition in the botanical market, the ASPRM is unlike anything ever produced before, and therefore, will remain the primary product of its kind. The current competition of the ASPRM consists of 3D scanners used for CAD modeling. Although these scanners are complex and well-designed, they are only able to complete one scan at a time. The ASPRM, on the other hand, is able to produce many scans in a specific period of time, therefore producing much more data in a shorter amount of time. Additionally, these other scanners are unable to string these scans together to create 3D point cloud like the ASPRM is able to. Other products that may be somewhat comparable to the ASPRM are various 3D scanners that are attached to a robotic arm. While these devices are able to scan and produce 3D images, they are only used for small objects and are predominantly utilized in 3D printing. Moreover, these scanners only are able to produce one scan at a time. On the other hand, the ASPRM has virtually no limit on how large of an object it is able to scan, is utilized for a variety of purposes, and may produce several scans at a time. In fact, no other item on the market creates multiple 3D point cloud images strung together at different time intervals, may be used for mass harvesting, is able to manipulate an object, and can identify structural components, color, and heat of an object all at once. Despite the need for the ASPRM, the future promises little to no competition, as well. Currently, there is not much research in the area of automated harvesting and robotic plant development analysis, so it is unlikely that, by the time the ASPRM enters the market, there will be much competition.

Although the ASPRM is an innovative, revolutionary piece of technology, there are some key risks in introducing the ASPRM to the market. The most obvious of these risks is the fact that the ASPRM requires a high initial price of production. Therefore, stakeholders may be weary of investing in the ASPRM. However, after an initial investigation of the benefits the ASPRM offers economically over time, this issue will become null. Another risk of introducing the ASPRM to the market is that the product will replace human labor jobs, and therefore, may affect the economy over time. This may be seen as beneficial, however, as fewer hands on a job may result in higher wages for each individual, thereby increasing one's financial potential.

The commercialization approach of the business centered on ASPRM is detailed to ensure the success of the commercialization of ASPRM. The mission of the business is to encourage a world where produce is plentiful and plant development is researched with ease in hopes of a healthier, more nutritional future for the every human on earth. With advanced technology readily available, the ASPRM has the potential to be available to the world as a whole in the near future. While it may be a while until it is able to feed the world in mass quantities, this is still an obtainable goal in the future. Given the rise in interest in environmental health and physical health in humans, it is best for the ASPRM to enter the market as soon as possible in this substantial window of opportunity. Additionally as part of the commercialization strategy, the ASPRM offer several potential economic benefits. One benefit is that the machine offers a continuous source of income as it is rented to different agricultural or research-based companies. This is in addition to the income generated as a machine is sold to larger companies. Over time, these revenues compounded with investors' contributions will result in a return of investment and, eventually, a surplus of income. In the future, revenue will increase drastically as companies find that the implementation of the ASPRM results in higher income. This will likely happen due to the increasing cost of human labor, thus decreasing the expense of the machine for the ASPRM client. Consider, for example, the price of immigrant human laborers picking strawberries in the United States. As immigrants leave the country, the need for an affordable source of labor arises. In order to compensate for the human labor, the ASPRM will only need to pick as many strawberries over a certain period of time as a human would. Given the ease of this task, the ASPRM will readily recompense clients for rental fees, thus encouraging further renting and purchasing of the machine, thereby increasing the demand for the ASPRM.

Along with the ASPRM's unique commercial benefits comes its potential for societal impact. In this current era of modern technology, roughly one out of every nine people in the world are either going hungry or are malnourished. The modernization of food harvesting has made dramatic advances in the past century. Planting and harvesting grains such as corn and wheat are now done entirely with large machines. These machines multiplied the quantity and efficiency of grain produced by immense proportions. However, humans cannot rely solely on grain to survive. They require other sections of the food pyramid to have a well-rounded, nutritious diet. Produce is a crucial element of the food pyramid, and it has not had any technological advances towards harvest in the past century.

The ASPRM is the first step toward advancing produce harvest technologies. While it may be infeasible to compare the ASPRM to a human gatherer in terms of quantity and speed at this point of its development, expected reductions of price and efficiency of design will soon outweigh the average human harvester. This will result in more affordable produce in greater quantities, thus enabling a healthier world. In fact, while the ASPRM may be used readily in individual companies and research labs, the potential the ASPRM has to benefit the world is staggering. The ASPRM's unique ability to both harvest and analyze produce in mass quantities offers the ability of a single, revolutionary machine to feed the world when utilized in mass quantities. This will most significantly impact groups who suffer from malnutrition in sizeable proportions such as those who reside in third-world countries and underprivileged citizens who reside in more privileged countries, including orphans, homeless people, and jobless citizens. These groups, with the help of the ASPRM, will be able to purchase the more-affordable produce in larger quantities, thus enabling these people to experience nutritional diets and eventually improved physical health.

Despite the ASPRM's societal benefits, there are a few issues that the machine poses. Given the machine's automated technology, the ASPRM is not recommended to be in the immediate presence of children without adult supervision, and it is advised that those working with the machine be cautious of its automatic movements. The ASPRM may require maintenance as any machine would; however, care of the machine is covered under rental and may be acquired with purchase of the machine. Additionally, as food evolves either naturally or manually, the program for determining which food is ripe may need to be updated. As the ASPRM enter the market, the machine will require regulation as it has the potential to be misused. One example of the potential misuse of the ASPRM is that a person may program the machine to poison produce or destroy crops. However, it is necessary to note that this should not defer potential customers of the ASPRM as this is just as probable with a human laborer.

The Automated 3D Scanning with Precise Robotic Manipulation offers a host of commercial benefits, including increased wages, while simultaneously offering societal benefits, such as easing the grasp of malnutrition. The ASPRM is a revolutionary piece of technology that is sure to produce a brighter, healthier future for the world as a whole.

Technical Discussion and R&D Plan (min length: 4 pgs, recommended length: 4-6 pgs)

During development, there are significant technical challenges we must overcome to move forward with our project. Some of these challenges require expertise from outside of our field of study. Other challenges require time and experimentation.

The first challenge that we faced was determining what to use as a base for our observation table. After consulting with The George Washington University machine shop, we decided to use a piece of equipment they had left over from a previous project. The piece was a four foot diameter metal table with a ball bearing arm attached to the underneath side of the table. This arm was able to circumnavigate the table and was strong enough to hold a substantial amount of weight without breaking.

The second challenge that we encountered was determining how to motorize the arm on the base of the table. The motor needed to be able to precisely increment the arm around the table by receiving a signal from a Raspberry Pi. It also needed to be powerful enough to spin the arm around the table in less than thirty seconds. The holding torque of the motor also needed to be strong enough to prevent slipping of the motor if it was pushed on by an exterior force. After consultation with our friends at The George Washington University machine shop, we decided that a stepper motor in conjunction with a timing belt would be the most efficient way to motorize the base arm. Afterwards, they helped us fashion a mount for the motor on the table. Additionally, we required assistance in building the circuit for the stepper motor, motor driver, power supply, and Raspberry Pi.

The third challenge we faced was finding motors to motorize the joints in the camera arm. This was especially difficult because of the vast variety of motors options we had to choose from. After consulting with The George Washington University robotics lab, we decided to invest in Dynamixel servo motors for the arm joints. After a month of development with these motors, we realized they were not powerful enough to lift the arm joints under specific torque requirements. Also, the motors would not hold position in the event of a power failure. This would cause severe damage to our machine. Additionally, the software interface we were given to run the Dynamixel motors was not well documented and had broken functions. After scraping the Dynamixel motor idea, we were back to the drawing board. Our solution was to use linear actuators. Currently, the linear actuators are proving difficult to get working because there is no documentation for how to program them with a Raspberry Pi.

The fourth challenge we expect to face is building an algorithm that takes in the readings from the Xbox Kinect camera and calibrating the position of the camera arm relative to the table. This will involve lots of repetitions and motor calibration.

The fifth challenge we will face is building an algorithm to efficiently scan an object. After a greedy scan is performed, the efficient algorithm will use the point cloud data of the scanned object to find an optimal set of camera arm locations to scan from. The algorithm will eliminate camera positions that produce the same results after a point cloud image of the object is constructed.

The main risk we will encounter in development is getting caught in unexpected amounts of time spent learning how to program a piece of hardware. When bringing this product to the market, manufacturers may opt for different hardware. If this happens, we will have to spent a significant amount of time re-calibrating the system.

The five challenges listed above will be our focus in stage one of production. Additionally, we will build a tilting platform to be placed at the end of the camera arm for the Kinect camera.

Our observation table with robotic camera arm will be fully motorized. The camera we will be using is an Xbox Kinect 2 camera. It is connected to a PC using a USB cable. A Flir Lepton thermal sensor is attached to the Kinect camera. It communicates with a Raspberry Pi GPIO pins using the SPI and I2C protocols. The thermal data gathered from the Raspberry Pi is sent over an ethernet cable to the PC. The interface for taking images with the Kinect camera and thermal sensor, written by Andrei Claudio Cosma, is programmed in C++. It uses libraries from the Kinect SDK, OpenCV, and bcm2835.

The motor that powers the base of the table is a Nema 23 Stepper Motor. It pulls a timing belt that is attached to the center of the arm. The Nema 23 Stepper Motor is combined with a 2/4 phase Nema 23 Stepper Motor Driver that is connected to a Raspberry Pi 3. The Nema 23 Stepper Motor powered by a Switching Power Supply 350W 24V 14.6A for CNC Router Kits 115V/230V S-350-2. The script for stepping the motor is written in Python. The script features a function to turn the motor in either direction by a specified number of steps. It also features an acceleration and deceleration function that will incrementally increase and decrease the speed of the motor when starting and stopping motion. Using this function prevents physical damage to the motor.

The two linear actuators are used to motorize the joints in the camera arm are ServoCity 12” thrust heavy duty linear actuators. They are connected to the same power supply as the Nema 23 Stepper Motor. Both of the linear actuators are connected to an Actobotics Dual Motor Controller. The power supply feeds 24V to the Dual Motor Controller, but the linear actuators run on 12V so a 12V step down converter is used to do this. The linear actuators have built in potentiometers that allow us to read their positions. Using the potentiometer readings, we will write a Python script to move the linear actuators to a predefined position. The linear actuators move slowly enough where we do not need to write acceleration and deceleration methods. Furthermore, in the event of a power loss, the linear actuators will hold their positions. This feature highly influenced our decision to get these motors. Finding the proper positions to mount the linear actuators on the camera arm joints required some optimization mathematical calculations. After solving these equations, we found the placement of the linear actuators on the joints that optimized the total range of the joint’s motion.

The Kinect camera is placed at the end of the motorized camera arm. However, with the two linear actuators alone, the camera will not have a wide enough field of vision to accurately take pictures from all angles of the object on the observation table. To solve this, we will build a motorized tilting mount for the Kinect camera to sit on top of. This will be able to tilt the camera with a range of over 200 degrees, expanding the field of view to more than 230 degrees. The tilting mechanism that the Kinect camera will sit upon is a CM-785HB Servo Gearbox. Like the linear actuators, the servo inside of the CM-785HB Servo Gearbox has a potentiometer that gives position readings. We will write a Python script that will use the servo’s potentiometer to move the servo to a predefined position.

After all of the motors are running and can be programmed to move to a desired location, we will write an algorithm that can move the camera arm to any designated position within the camera arm’s range. This will require the implementation of inverse kinematic equations. Inverse kinematic equations are used to determine the optimal positions of the joints in the camera arm so that the position of the end of the camera arm is in a specific location. We have not yet determined if we will use an open source inverse kinematics library or build our own. When we have an implementation for inverse kinematic equations, we will write a Python script that will move the motors to the positions acquired from the output of the inverse kinematics equation solver.

With a camera arm that is fully motorized to move to any desired position, we will then be able to build an algorithm that will move the camera arm to enough positions so the combined scans can create a full three dimensional model of an object on the observation table. The question is, what positions should we move the camera arm to so that it captures a full scan of the object? In order to solve this, we will take two approaches. The first approach is to write a greedy scanning algorithm. The greedy scan will move the camera arm to a set of predefined positions that will ensure that all of the angles of the object on the observation table are seen in the Kinect camera's field of view. The greedy scan will ignore the fact that it will take redundant photos. This will cause performance issues because taking more images for the scan will require much more time.

To solve the issue of wasted time and data from taking redundant photos, we will create an optimized scanning algorithm. The Kinect camera offers a wide camera view. After an image is taken, we will send the image to our computer vision software and it will begin building a three dimensional point cloud representation of the object. After the point cloud representation of the object is updated with the image taken from the current location of the camera arm, our algorithm will use the point cloud representation of the object to determine the next location for the camera arm to move to so it can capture an image of the side of the object that is not yet in the three dimensional point cloud representation of the object. When compared to the greedy scanning algorithm, this optimized scanning algorithm will greatly reduce the number of scans required to create a three dimensional model of an object. Furthermore, this algorithm will reduce the amount of time spent scanning the object.

The optimized scanning algorithm is innovative because when the Schunk Robotic Arm is using the Kinect camera scans to interact with the object on the observation table, the three dimensional model of the object will need to be updated after every major interaction the Schunk Robotic Arm performs on the object. The optimized scanning algorithm will reduce the amount of time required for the Schunk arm to interact with the object. This will benefit target applications because the speed of scanning and interaction with an object will be reduced.

The key objectives to be accomplished during Phase I research are as follows: First, we will construct the observation table with the support of The George Washington University machine shop. Next, we will write a Python interface to run all motors on a Raspberry Pi 3. Then, we will implement an inverse kinematics equation solver that will determine the positions of the joint motors required to achieve a predefined camera position. After the inverse kinematics equation solver is implemented, we will write an algorithm that will move the camera arm to a specified location. When we can move the camera arm to a location, we will be able to build a greedy scanning algorithm. In order to optimize the greedy scanning algorithm, we will need to use our computer vision software to interpret the three dimensional point cloud representation of the object it is scanning. After we can iteratively build a three dimensional point cloud representation of an object after successive images of different camera angles, we will be able to write an optimized scanning algorithm.

When we have an optimized scanning algorithm that will be able to scan an object on the observation table, we will begin implementing the Schunk Robotic Arm into our system so it can interact with the object on the observation table. First, we will create a Gazebo simulation of the camera arm. Afterwards, we will combine the camera arm Gazebo simulation with the Schunk Robotic Arm Gazebo simulation and create a world simulation of both objects. The final step is to build a user interface for running the machine and using it to gather data and interact with an object placed on the observation table.

There are several questions as to how to determine the technical and commercial feasibility of the product: What are the best motors to use in construction of the camera arm?

How do we build the electrical circuit for the motors? What is the best way to account for drift in the motors? In the event of a power loss, how do we prevent the camera arm from collapsing, resulting in the destruction of our machine? How do we implement inverse kinematics for the camera arm motors? How do we use the camera readings to determine the relative position of the camera arm? How do we create an algorithm to optimize a scan of an object? These questions must be answered during our innovation process so that our product can be successful.

The critical technical milestones of the project that must be met to get the product on the market are as follows: The observation table must be constructed. A Python script for running the motors must be implemented. An algorithm to solve inverse kinematics equation must be implemented. A Python script to move the camera arm to a desired location must be implemented. A algorithm to create a greedy scan of an object on the observation table must be implemented. An optimized scanning algorithm that uses the Kinect camera's images must be implemented. A Gazebo simulation of the camera arm must be created. The Gazebo simulation must be merged with the Schunk Robotic Arm simulation into a world simulation. A user interface to control the system and gather data from it must be implemented.

Research and Development Plan:

May 2016	Construction of the observation table.	Collaboration with the GWU machine shop.
May 2016	Raspberry Pi 3 setup.	Install Ubuntu distribution.
May - Sept 2016	Determine what motors to use for the joints in the camera arm.	Base: stepper motor Joints: linear actuators Tilting Mount: servo gearbox
May - Aug 2016	Stepper motor construction.	Build circuit for stepper motor with driver and power supply. Construction of hardware to attach the motor to the table.
Aug 2016	Stepper motor controller implementation.	Python script to drive the stepper motor. Acceleration/deceleration methods.
Oct - Dec 2016	Linear Actuator controller implementation, construction.	Build circuit for linear actuators and implement a Python script to move the actuators to a predefined location.
Dec 2016 - Jan 2017	Servo Gearbox camera mount tilt system implementation and construction.	Build circuit for linear actuators and implement a Python script to move the servo gearbox to a predefined location.
Jan - Feb 2017	Inverse Kinematics	Create a Python script to move all motors to a predefined camera location.
Feb 2017	Greedy Scan	Create an algorithm that will make a greedy scan of an object on the observation table.