CALIFORNIA STATE UNIVERSITY, SACRAMENTO

ADVANCED ROBOTIC MACHINE:END OF PRODUCT DOCUMENTATION

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May 2nd, 2016

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III. Executive Summary

The apparent problem of recycling material is the amount of energy and cost the process consumes. In the USA there has been a rampant increase in the amount of efforts put into recycling materials such as paper products, aluminum, and other metals. Recycling has also become an incentive for businesses and government efforts because of legislation and green efforts. To solve the issue of energy/efforts a much more economical and conservative solution would be to reuse as much products as possible without treating any of the materials. Reuse instead of recycling is a more efficient. The case being examined is that of an assembly line's use of cardboard mailing sleeves that are required to ship mail. To solve the issue of recycling, we have built a robotic arm system that employs a vision system to identify cardboard that meets criteria for redeployment into the assembly line system. We have created this solution for DST Output, they will be using this robotic system for sorting the good/bad cardboard on their ground floor for redeployment. In creating this solution we have examined the numbers behind recycling vs reuse, domestic and international production costs and marketability of this solution. A work breakdown structure was enacted in order to organize and scope the work needed to complete the project on time. All members of the group were responsible for different aspects of the project. Risk assessment and mitigation plans were developed during the creation of the project as well to ensure that the project could be finalized in the scheduled time. Mitigation routes were mapped out and some routes were taken after testing results proved in inaccurate. During the creation of the project we encountered many issues and bugs that were not expected, with the limited time constraint we have solved most of the issues and have a working prototype. This prototype will increase the conversation of reuse vs recycling and will shed light on an area practical applications of machine vision that are open sourced and free to use.

IV. Abstract

***Abstract*—The motivation to improve efficiency and learn new engineering strategies leads people to take on great challenges. We as a team decided to tackle the challenge of reducing impact on the environment by reducing the amount of recycled cardboard used in shipping mail. Taking a cardboard sleeve from a stack and sorting it based on criteria that determines how reusable it is, is one of those challenges. Using a robotic arm in conjunction with a multiple systems, we attempt to accomplish such a task. We began by determining what kind of systems would be needed to accomplish this task, as well as the design and modeling of a robotic arm. The approach to the solution will involve many different aspects of engineering and resourcefulness, and this paper will entail that process to reach our desired objective. In this report we discussed our journey in completing this project. We discuss our initial design idea and our feature set. We also discussed our project schedule, milestones, and how the project was broken down among our members. The goal of this project was to use the skills we learned and attempt to solve a real world problem.**

V. Keywords

Keywords—Vision system, vacuum system, robotic arm, motion control, cardboard sleeve, pneumatic, PSI, PLC, vacuum pump, stress test, risk assessment, mitigation plan, test process, tests results, cardboard, image processing, software testing, physical testing, re-usability.

VI. Introduction

In the world of Engineering, many problems and challenges develop, and these obstacles range from societal to mechanical to biological issues and so on. And as our technology continues to rapidly advance, many companies face emerging societal issues that do not necessarily fit-in with their business models. The paper and pulp industries are just one sector facing many emerging issues. A fundamental area of improvement for paper and pulp industries lies in reducing the amount of forest resources they consume. With this in mind, our team was challenged to improve the amount of forest resources such industries use, with our focus primarily on DST Output, an American software development firm that specializes in information processing and management reuses.

Growing up as a child, we all heard of the "reduce, reuse, recycle" chants throughout schools and our team wants to place an emphasis on the second "R", reuse. By reusing the same material several times until it is in no condition to function, but can only be recycled, can save companies not only money, but can benefit our environment through a more efficient recycling system. A bright example of a company that can adopt this system is the United State Postal Service (USPS). According to USPS, "mail trays must be secured using USPS approved cardboard sleeves," and their shipping boxes cannot be reused for any other purposes, but that of USPS because it will be considered a federal crime [32]. With the vast amount of research performed for this problem, our team concluded that reusing cardboard sleeves as many times as they are capable of being used, will yield in a more efficient recycling system and reduce the consumption of forests. This approach reduces the environmental impact of the cardboard by completely removing the energy, chemicals, and resources needed for the recycling process. Aside from freeing the resources needed for recycling, reusing offers the benefit of making the material, in this case the cardboard sleeve, immediately available for use.

Not only was our team trying to be maximally efficient in the re-usage of the cardboard sleeves, but our aim was to automate this task, since it would also benefit our sponsor. Automation of manufacturing tasks has been seen by companies as a way to save money by eliminating repetitive and monotonous tasks in a manufacturing process. While reducing the cost of producing a product, automation also keeps the product uniform and consistent, while allowing more products to be produced. For companies that mail large amounts, they often deal with the United States Postal Service, which has regulations regarding how mail trays have to be shipped. Mainly, it must be secured using a USPS approved cardboard sleeve so that the contents will not spill or be accessible and [32]. This means there is a person that takes a sleeve from a pile or pallet, then places it on the mail tray. This is repeated for every mail tray that comes by, and has to be repeated for the entirety of their shift. This creates an expenditure for a company that has to ship mail in mail trays. Therefore this would be an ideal task to automate since it is repetitive, labor intensive, and does not require much skill.

Although technological advancement has led to many tremendously fascinating inventions, not all of the inventions are ecologically positive. Not only is DST's problem in the lack of automation, but it also lacked efficiency. This inefficiency consisted of two things: no automation and environmentally wasteful in their resources. Our team designed and implemented a robotic arm prototype, which purpose is to solve the problem of sorting cardboard sleeves autonomously, while being maximally efficient and environment-friendly. This paper reveals our team's current design and our prototype's abilities, as well as key understandings of how our robot differentiates between a cardboard that can be reused again and a cardboard that needs to be recycled. Equipped with a visual inspection system, our robotic arm uses machine vision to perfect the process of separating the reusable from the non-reusable, recyclable cardboard sleeves.

To simplify our design, our robotic prototype arm consists of four main systems. The robotic arm structure, the motion controlling system of the arm the vision system, and the vacuum system. The essential function of this arm is to visually inspect the detected cardboard sleeve and position the cardboard sleeve for a stress test - a test that determines if the cardboard sleeve is malleable, compared to a specific threshold - to differentiate between good and bad cardboard sleeves.

Properly organizing and distributing the workload amongst our team members was the beginning of our project management. The workload was broken down into the main features our project possesses, then the tasks those features have, and the sub-tasks those tasks address. This paper also reveals our main components for our robotic system that have been distributed between each member, shown below:

1) Vision System
2) Vacuum System
3) Robotic Arm
4) Motion Control

Our main source of our budget is our client, DST Output, which was able to provide equipment and software for our major components of our robotic system. This paper also illustrates the design, the workload, our current time-line, and risk assessment for each of the components listed above. Future implementations, obstacles, and speculations were also included for each section listed above, to help understand our possible ways of improving our robotic arm.

When designing and implementing most robotic systems, many risks arise because of the complexity of such systems. There are many risks to keep in mind when building such a complex electromechanical system. Erecting a system as such, requires many resources invested. One must keep in mind that our robotic system is not error-free and many of the components are dependent upon one another. Our project ARM can be categorized as a complex and as a potentially full-of-risks system. The risks that our team assessed can be classified as major or the most essential risks our system can encounter. One must be aware that all the risks of our vacuum system cannot be addressed due to the fact that they're either insignificant or have minimal impact on the overall system.

VII. Societal Problem

The societal problem we aim to address is that of waste. Reusing material instead of recycling saves energy and money. The solution we have developed helps increase the re-usability of cardboard for the sponsor that is supporting us. The robotic arm increases the incentive to reuse instead of recycling paper products because it is automated and does not require much knowledge to operate. Incentivizing companies to reuse their products instead of recycling is what we hope to accomplish by giving this system to our sponsor. The software developed uses fundamentals of an open source machine vision library that is free. This means that any company that wants to implement something similar to our solution can do the same for no cost at all. The libraries used have a large community of support behind them and do not require any special licencing. This is a driving force when it comes to creating a custom vision system that can serve multiple needs. Most control companies that produce mechanical arm solutions do not incorporate any type of vision system on them, instead they have many different sensors to do simpler more repetitive tasks. This makes our system much more unique because its main feature is its vision system. This vision system is free and only costs the time it takes to create the program needed to evaluate. This should have other companies taking interest in such a relatively low cost solution to reusing their materials. Inspiring reuse through vision related evaluation is one of our goals. If we are successful at this goal that means that other companies will increase their reuse efforts and salvage more of their products, thus decreasing pollutants and costs. We could have gone the route of keeping our solution private and in turn tried to pitch this product around. This however would not inspire businesses to innovate vision solutions. Decreasing costs of a solution and increasing innovation will lead to other businesses realizing that they also can implement such systems.

VIII. Design Idea and the Feature Set

A. *Description of the Design Idea*

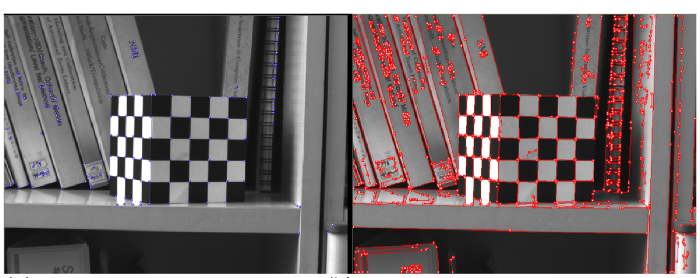
Our idea is to create an automated robotic arm, with a computer vision system, to accurately sort through cardboard sleeves for maximum efficiency of reusing cardboard. The robotic arm may not be as advanced as the robots, which larger robotic industries provide, however, it will be much less costly. The low cost of the robotic arm may motivate smaller companies to look into this solution and use it to save on finances, spent on buying new cardboard sleeves. Our robotic arm will pick up cardboard sleeves from a pallet, inspect them for durability, and properly sort them.

Our idea is unique in the sense that our idea focuses more on reusing the cardboard rather then recycling it. We believe that Americans' have learned to recycle cardboard, but because of the energy required to recover the cardboard for other future purposes, we believe in climbing the hierarchical ladder. There may be many people encouraging the re-usage of cardboard by showing the environmental facts of how many trees could be saved. However, saving finances for businesses may provide better motivation. The technologies needed for our design were only recently developed within the last couple of decades. However, the lessening costs of this technology and the increase in the competition of product sales, has advanced robotic machines to become more and more affordable. With this solution, which is becoming more affordable with every year, we can start helping companies with poor reusing habits. This solution can certainly grab their attention and bring interest to reusing corrugated cardboard.

The general system we have chosen as our solution consists of multiple features in order to address our design requirements. These features will be examined in depth in a later section of this document. Our design requirements are our constraints and our goal checklist. These five main points presented below are the key aspects to how our system will address the selected solution. Each of these key aspects will be explained:

- Identifying Cardboard Sleeves
- Picking up Cardboard Sleeves
- Visual inspection
- Physical Inspection
- Movement

1) Identifying Cardboard Sleeves: The first point of interaction in our process is the detection of a cardboard sleeve in the environment. This process will engage the visual system feature described later in the document. Essentially what is needed for the system is to know where a cardboard sleeve is in three dimensions, and if it can be detected. After the identification process has completed, the system should alert the robotic arm to complete its next task. This initial task is a crucial entry point to the rest of the tasks to be performed and if not done correctly, the rest of the system will fail. Multiple features will be implemented in order for this task to be completed such as: a state machine, a visual system, and the interaction of the motors. Thus this task is no simple feat because it will implore multiple aspects of our system in order to successfully complete its goal. A reference photo from an image processing focused journal can be seen below in Figure 1, which directly relates to how our cardboard sleeve will be detected [1].



(a) (b)

Fig. 1: Example of Edge Detection. [1]

2) Picking up Cardboard Sleeves: The next part of interaction in our system of detecting a cardboard sleeve would be to interact physically with that cardboard sleeve in question. This process will engage the arm structure and servo interaction, as well as the suction component of the system. When looking to see what features are being implemented to achieve this goal, we can see that the programmable logic controller (PLC) will instruct the servo movement through its internal state machine. This interaction will consist of turning on the components needed for the suction cups to do their job with the correct amount of pressure. Another feature being used to achieve this goal is the arm itself. The construction of the arm, as the mean of contact, is a crucial feature that needs to be completed in order for this requirement to be met. These steps in the process will be needed to take the cardboard sleeve into its movement phase. The key end defector (suction cup) can be seen in the Figure 2 .

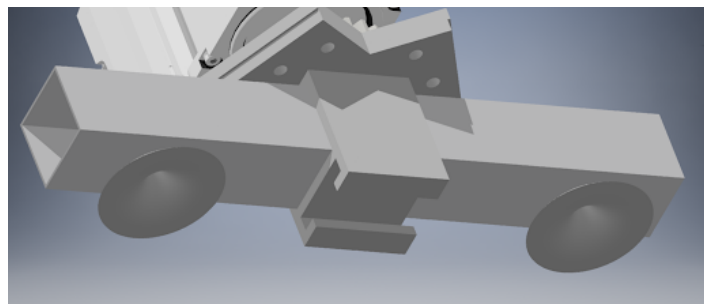


Fig. 2: Model of End Defector. [2]

3) Visual inspection: The next step in the process would be to visually inspect the cardboard sleeve for quality. This requirement will mainly be using the visual system to complete its goal but will also be utilizing the feature that allows the arm to grasp the sleeve because the sleeve will need to be held. The sleeve will need to be held in a static position in order to do image processing on the sleeve in question. The inspection process will begin with a photo being taken and sent to the image processing tool, and evaluated against our criterion for a bad cardboard sleeve. This step's outcome will be presented by the PC aspect of the system and will be pushed into the state machine process for further instructions. This requirement will use the same basic features that the cardboard sleeve-identification-requirement used. However, it will be implementing these features in a different manner.

4) Physical Inspection: The next step in the process after the visual inspection would be to physically inspect the cardboard sleeve. This is a vital step in checking the quality of our object. This part of the process will entail multiple features that pertain to stress testing the flexibility of the object. This crucial step will take data and interpret it by the PC in the system. The output of the PC will be sent to the PLC in order for the PLC to make a decision which state to pursue next.

5) Movement: One of the most necessary requirements for this process would be the actual movement of the cardboard. This requirement will be an intermediary to all other requirements because it will be the means of allowing all of other requirements to begin. The requirements for moving the cardboard will perform quality checking and picking up the cardboard. Some of the main features the design will implement will be the suction system and the PLC's path planning algorithms. The PLC will need to interpret and send coordinates of 3-dimensional space. The output signals sent to the motors will need to execute in a precise manner in order for a path to be reached.

B. Features

The features set explained below, describe how we decided to split the project up amongst ourselves. Each feature had a person assigned to it and that person was in charge of completing the feature to the best of their abilities. The features are grouped first into features relating to the vision, then followed by those that are related to the vacuum system, motion control and the robotic arm. The last feature is related to the physical inspection of the cardboard. These features combine to form what is now our robot. The arm and base structure serves as a skeleton, the vision as eyes, the motion control as a nervous system, and the physical integrity test as the tactile feeling for the robot arm.

1) Simplified Picking(Bin Picking): In the first revision of the design idea the idea of Bin-picking was the original plan. We have found that plan of action to be overly burdensome and not needed as a simpler solution was found. The solution we found was to instead use the vision system to identify a landmark that is common on all the cardboard targets. Once found the PC will communicate with the PLC to reorient the end defector to the proper position. This is all done in a clock-wise manner with decreasing height. The plan is to have the arm move about in a clock-wise manner to the next sleeve while slightly repositioning itself to best pick of the new sleeve in question. Every time a single layer has been processed the arm will drop in height in order to better position itself for the next layer. While the cardboard stacks are not in a perfectly symmetrical stack they are very roughly in each quadrant on the stack, therefore the need for bin picking is overly arduous. Instead the best solution is to position the arm where we believe the subject is and then adjust as needed. Adjusting the position is the process of path planning

The first type of implementation is the single query planner, such as the rapidly exploring random trees (RRT), and single query bidirectional probabilistic road map planner, with lazy collision checking [33]. These type of planners are able to handle changing environments and collision detection and require a high computational effort [33].

The second implementation is the multi-query planner, such as the probabilistic road map planner [33]. A probabilistic road map takes samples of the configuration space that are free of obstructions, and connects them in a road map of feasible motions [34]. As a result, using this type of planner assumes that multiple samples are to be taken in the same workspace [33]. There still exist other types of path planners, and some companies have proprietary software which has a built in path generator for robotic applications [35].

For our design we plan on using the bin picking strategy of picking the topmost cardboard sleeve. Ideally they would all be on one of the four stacks on a pallet, but since in real-world applications they could overlap each other. Thus, we would look for the sleeve that is not covered up by another sleeve. This allows us to see the top of the stacks as a plane, from which we choose one of the four sleeves visible. The second part of the bin picking implementation is the path planning. The strategy for path planning will be determined by the capabilities of the B&R automation studio software. For example, the software allows us to distribute the processing of set points for all the axises to multiple drives [35]. This software will allow us to perform complex motion sequences, while keeping the simplicity of the code we will write [35].

2) Vision Software: To have our system be able to interact with objects, it needs to have a reliable and easily managed interface. This interface that will translate real world objects into virtual objects is most notably referred to as Machine Vision (MV). MV methodology is vast and employs many different techniques and languages. While it is a very general field of processing, recently there was some standardization of techniques, making the task of creating MV solutions more clear and concise. To give a general overview of what makes up an MV solution, we need to examine the common steps taken in industry. Firstly, when creating an MV solution, usually an image is acquired of the object or area in question. Secondly, that image is then ran through processing to directly interpret what is in the image, which is commonly called image parsing. Data is then used to make decisions based on information collected from the parsed image. The next step is to have a system make decisions based on that data and output whatever result is required by the specification.

This feature that will be implemented will be that of a machine vision type solution, that will grade our cardboard sleeve objects in order for the system to determine an output. Firstly, the arm of the system will find its path toward the next cardboard sleeve in question and then using an on-board camera near the end defector, a photo will be taken This photo will then be sent to either a local single-board PC or a remote PC to be processed with MV style techniques. Based on the outcome of the image processing a state machine will decide whether to continue with further evaluation of the object or if the object will need to be discarded. If the object passes a quality check at this point , the object will continue to the next test which will again be another photo acquisition. This acquisition will be a photo of the opposite side of the cardboard sleeve. The photo will then be processed again in the same manner as the first image and based upon the resulting outcome the state machine will decide whether to discard or continue on to further evaluation of reliability. These are the only two testing phases that will be apart of the vision interpretation system. This was a general overview of what the feature consists of and now that there is a general understanding, we can now dive into more detail of the techniques to be used and how it will be done.

3) Gripper Type: Since the modernization and industrialization of our technology, autonomous robots have progressed in their designs, ranging from enormous machines with heavy-duty lifting capabilities, to robots capable of performing nanoscopic tasks. Just like a human being has arms, legs, ears, eyes and so on, humans consider several parts of the body as essential to being able to perform a task. The task of lifting objects with an arm requires a functional hand and the ability to grasp that object. In the same manner, we can consider the robot arm of a robot as one of the essential functions it cannot perform without. Specifically, a robot that is intended for performing grasping and lifting consists of the robotic gripper, which is one of the most valuable pieces of this type of robotic system. Therefore, the choice of a robotic gripper is extremely important and must be chosen wisely. There are a variety of gripper types and one must consider the factors each gripper offers, and the task they're trying to perform. According to Mohammed Karokh, the most common gripper types are: "jaw-type, vacuum and magnetic grippers" [36]. To decide which type of gripper our robotic system needs, we need to consider several major factors to maximize our efficiency and productivity. These several factors include: the different types of gripping techniques, the material we are lifting, and the overall performance of the gripper.

As mentioned above, there are several different types of grippers that our design can theoretically support. Karokh, in his article, mentions three main groups of grippers, which consist of single-surface, magnetic, and vacuum grippers, and also mentions clamping, two and three jaw, and flexible grippers, which are sub categories of the three main groups [36]. In order to clearly understand why our team's choice of gripper type is a vacuum gripper, we must observe the most common gripper types known to robotics.

Single-surface grippers are self-defining because they grip only one surface of the object or material, and these types of grippers are handy in gripping "light and heavy weight and flat components." When it comes to these types of surfaces as described above, the single-surface gripper is the king. According to Karokh's article, the main single-surface gripper types that exist are magnetic, vacuum, and adhesive grippers [36]. Since adhesive grippers are mainly used for lifting irregularly shaped objects and different types of fabrics, they will not be addressed in our design.

On the other hand, magnetic grippers work by generating a magnetic field via a wire wounded into a coil. The magnetic field is activated when electricity is passed through the field and deactivated once the electricity stops flowing through the magnetic field. Usually single-surface magnetic grippers are used for steel scraps or iron, in which they can either lift very heavy objects, but can also be used for light-weight objects [36]. Since a single-surface magnetic gripper deals with conductive objects, it will be nearly impossible or not efficient to implement in our design.

All of the single-surface types of grippers mentioned here work by pulling the actual object to itself rather than pushing the object away, which is essential to our design [36]. Pulling is one feature our robotic gripper needs because our arm will be lifting the object. Since the surface of our object a cardboard sleeve is nearly flat, then this type of gripper type best suites our design. The only problem that arises is that cardboard is a porous material and not necessarily a flat surface, on a microscopic scale. To tackle this problem, a single-surface vacuum gripper is the key, with a powerful vacuum gripper. Thus our design will be implemented using a single-surface vacuum gripper.

Vacuum grippers, or also known as suction cup grippers, are known for their ability to lift porous objects or cardboard, as long as enough pounds per square inch (PSI) of pressure is applied. Another major component of a vacuum gripper is the actual vacuum itself. In order to supply enough power to lift our cardboard with a suction cup, it needs to generate enough PSI. An air compressor or an electrical vacuum will be used to generate enough PSI to get this job done. The advantage of an air compressor is that usually they are far more powerful and can be combined with a vacuum generator to generate compelling power. The figure below depicts a diagram of how an air compressor works with a vacuum generator to provide suction to a suction cup. In summary, an air compressor generates compressed air at a certain PSI, which flows through the vacuum generator. The vacuum generator squeezes the air at even more pressure, which creates a high speed of air flowing through the funnel. As this air passes, it pulls the air from the suction cup opening into the funnel, thus creating suction for the suction cup. The air inside the funnel is pushed out of the last opening in the vacuum generator, which the figure refers to as an "Exhaust" [3].

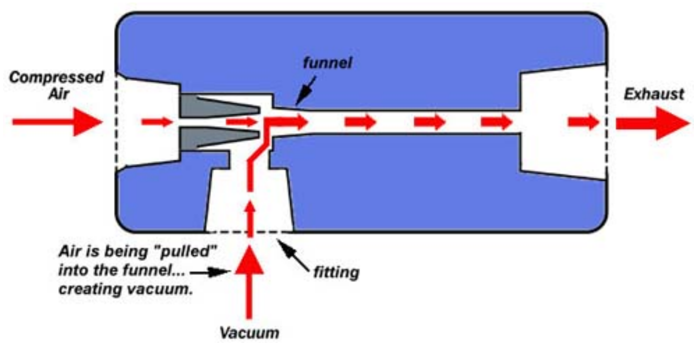


Fig. 3: Working Process of a Vacuum gripper [3].

There are also two types of grippers we have not yet addressed, which are clamping and flexible grippers. Clamping grippers can be designed with either a two-jaw or three-jaw or even custom made jaw gripper, with more than three grippers. If you look at your hand and push your thumb and index finger together in a grasping-like motion, it is essentially how a two-jaw gripper functions. Nothing complicated here. Now a three-jaw gripper is usually designed to have each piece of jaw at an equal distance away from one another, and its function is extremely similar to your hand once again, except that it is capable of having a better grasp. Since our object is a cardboard sleeve, and we need to lift it when it is lying flat on a surface, this type of gripper will be extremely inefficient, unless it is very precise and delicate with the cardboard. A similar argument can be applied to the flexible grippers. Flexible grippers can also be compared to a human hand because they are "indented to handle a number of different items," and can be different sizes [36]. Although flexible grippers tend to have the ability to be more delicate with objects, the design of a flexible gripper is an inaccurate design for lifting a cardboard box. Therefore, flexible grippers or jaw grippers would just not fit in our design.

Theoretically, any of the above grippers can be applied to our design, but a wise decision consists of several factors that we need to apply that will best fit our design. Applying factors such as the size, weight, the gripping technique, and overall performance of a gripper for our design, the vacuum gripper is the best choice by a mile. In comparison to the other gripper types, the vacuum gripper fits our design best because of its lifting technique, the surface it needs to lift from, and the type of material it will be lifting. Overall, a suction cup gripper with an air compressor and a vacuum generator is not just easier to implement in our design, but also more efficient and the best fit, as opposed to the other gripper types.

4) Base Structure: In any system, model, construction, or anything a human builds, a foundation is a fundamental part of the design. Unfortunately, not every foundation is correctly designed and we can sometimes witness buildings or constructions tilting, leaning, or sinking because the foundation had flaws in its design. Fortunately humans tend to learn from past mistakes and our design of the robotic arm requires a sturdy foundation as well. Many foundations or platforms exist for the base of a robot, and our team had to answer several questions before submitting to this design. The following questions helped us narrow down on our base design: is mobility of the base required? how much weight does the base need to support? how much material will this base use, and the total cost of the base?

The previous semester answered many questions for us. We now have a good idea of the materials we are working with and the support our arm structure will need.Our initial design for the platform had it at roughly 6 to 12 inches in diameter and more than 6 inches in height. The reason for these dimensions emerged from the idea of placing most of our robotic "brains" inside this base. Thus the base will be hollow inside with a few pillars holding the top lid of the base, see figure (Top View) below. Not knowing exactly how much everything will weigh, we are giving rough dimensions of our base, but once we have a better grasp of our equipment, the base size will accommodate our circumstances.

After gaining some insight into the needs of the arm structure, we redesigned the base to now be much bigger. The main difference is that the size of the motors are much larger and heavier than we had anticipated. This caused us to have more difficulty in properly gearing up the torque of the motors as we had planned and as a result we are moving the motors off the arm and onto the base. As a result our base is now bigger and shaped like an octagon. In the following image our old design for the base is shown. It it shorter and circular. This would have caused us issues during our initial test due to having many wobbly pillars as a support structure which would have caused problems during movement.

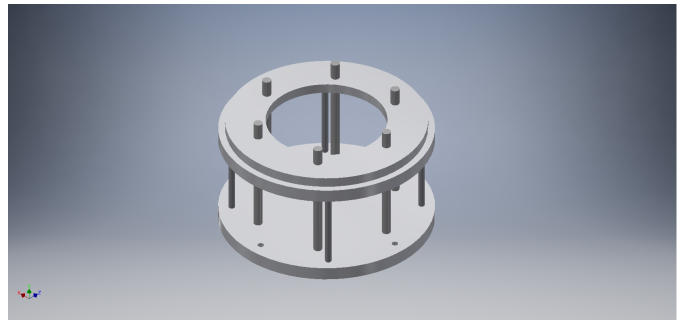


Fig. 4: Modeled Base Structure - Top View - [4].

During the fall semester, Aaron created a base that was built on differently than the one originally designed. The new version of the base has a Lazy Susan used for rotation and an rectangular top base. The non-rotating part of the base is made up of a 1 foot by 1 foot square that will need to be further modified to accommodate all the PLC hardware. By expanding the size of the base we can also increase the stability. One thing that is missing from our current design is a whole in the middle to allow us to pass wires and hoses through the middle of the base so as to reduce the amount of weight that is swinging around. In the following image the new design of the base is shown, without the middle hole:

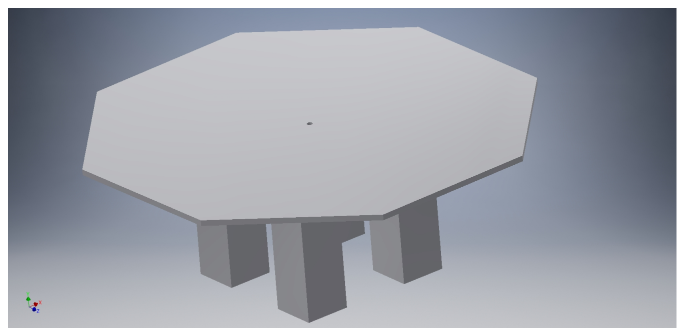


Fig. 5: Modeled Base Structure - Top View - [4].

The final result of the base structure looks slightly different than the fall semester. During the Spring semester, as we realized that the base needed to fit more things, Aaron rebuilt the base using a larger lazy susan, and a bigger space underneath. This design allows us to place a large amount of our plc items directly underneath the robot.

5) Arm Structure: The structure of a manipulation machine, depends on the task that is to be accomplished. There are a few key aspects to take into consideration. The first aspect to take into account is the required workspace to accomplish the task. The second thing to keep in mind is the degrees of freedom that the robotic manipulator needs to manipulate the object in order, to accomplish the task at hand. Another issue to keep in mind is the end effector, which is the part of the manipulator that directly interacts and grabs the objects in the workspace. Keeping these things in mind we can now take a look at some existing configurations for robotic manipulators.

As can be seen in figure 7 there are a few types of of manipulators. Each has its own merits and drawbacks.

The first kind of manipulator would be the Cartesian robot. The main feature of the Cartesian robot is that the three

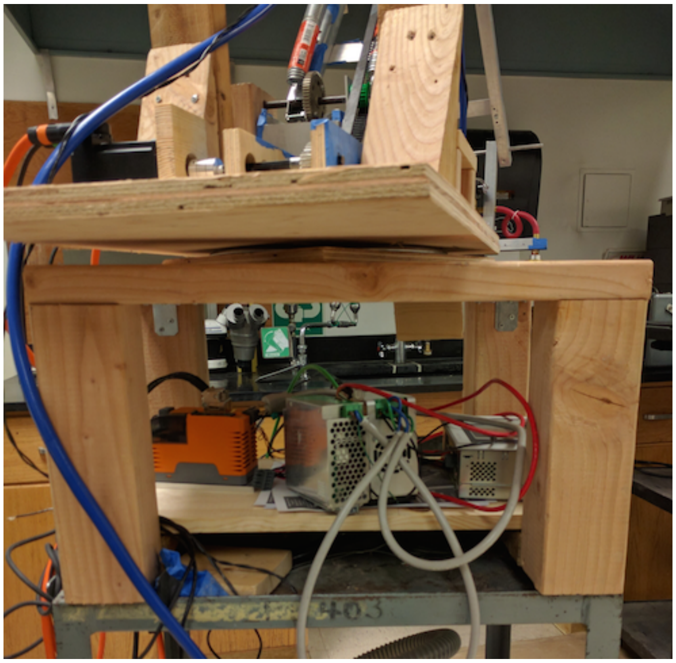


Fig. 6: Final Base - [5].

main axis are controlled linearly [6]. The types of motion required for this kind of robot is all translational and is usually accomplished with the use of worm gears.

The second type of manipulator is the cylindrical robot shown in figure 7. The cylindrical robot has 3 axis of motion, which are split into a translational Z axis, a rotational X axis, and a translational Y axis [6]. This gives the robot a cylindrical workspace, which makes it often looked over as a solution [37].

The next kind of manipulator is a spherical robot. This robot has a spherical work space, and for motion it has two rotational joints and one translational joint [6]. The workspace for this manipulator is spherical shaped, as described by the name.

The next type of robot is the SCARA, or Selective Compliance Assembly Robot Arm, manipulators. This manipulator is most commonly used in rapid assembly applications [37]. The workspace for this type of manipulator is a cylinder similar to the cylindrical robot, with a difference being that this iteration has two parallel joints that work in one plane [37].

The last manipulator type, is the articulated robot. This is the most versatile type of manipulator since the types of systems can vary in size and complexity [37]. The workspace for this type of manipulator is also a sphere, which adds to its versatility [6].

Taking all these types of the manipulators into account, our solution will be an articulated type of manipulator. This type of manipulator will give us some versatility in moving and interacting with our environment.

Our final design turned out to be very similar to our orginal design, with heavy modifications. For instance we only have 3 motors, that work to give us the motion we need. we also have added a belt to provide some motion to the robotic arm,

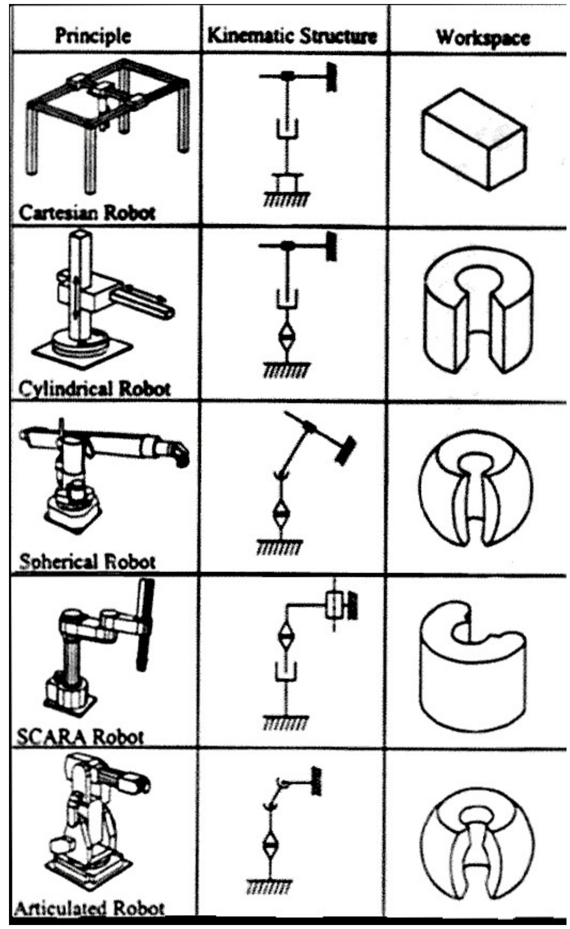


Fig. 7: Modeled Arm Structure [6].

and reduce the weight. The following figure shows the final design of the robotic arm.

C. System Control

1) Feature: The robotic arm will be controlled with multiple components working together. The major mechanical translation will be from motors that will be controlled by a programmable logic controller (PLC). There are multiple solutions to control our system however we will focus only on the ones we feel will satisfy our need in a cost and time efficient manner.

Choosing motors to control each moving part of the robot is certainly not an easy task. There are multiple types of motors available in many different variations. For our prototype robotic arm we will are using servo motors.

Initially we were thinking of using stepper motors. However after giving it some thought and after consulting professionals, we have decided that servo motors would be the best and most efficient solution for us. Using servo motors would increase the accuracy for our system, as well as make it less costly since our sponsor already has the motors in stock.

Fig. 8: Modeled Arm Structure [7].

Fig. 9: Servo Motor [8].

The PLC is also a very substantial component in our design. The PLC will be controlling all of the motors. This component will act as a secondary brain, a second node to our system, which will enclose all of the movement and translation logic. The PLC will be directly connected to each motor in our design, and will output appropriate signals to each motor in order to coordinate the robotic arm to reach the requested position. Once it reaches a certain position the robot will perform a certain task. After receiving input from a PC, through a state machine PLC will choose the next state to execute. The PLC will be getting its input from the PC. The PC will perform all cpu-intensive tasks such as complex calculations as well as image processing. The PC will output the data to the PLC which will analyze the input in order to decide the next appropriate state for the robotic arm to execute.

For easier implementation, the PLC was chosen to match the brand of the motors we will be using. Many industries which sell motors, also provide solutions for PLCs. Buying multiple components from the same vendor did not only make it easier for the components to interact together, but also provided us with good technical support from the vendor. For the PLC we are using the B&R's PowerPanel 420.

Fig. 10: Programmable Logic Controller [9].

e

2) 4-Point Bending Stiffness Test: Overuse of cardboard sleeves results in the deformation and flexibility of the sleeves. We have noticed that a large percentage of damaged, non-usable cardboard sleeves are very malleable. Testing the stiffness of the sleeve can help predict its durability. This 4-point bending test will demonstrate the stiffness of a cardboard sleeve.

Using two stands for support, the robotic arm will lower the cardboard sleeve and place it upon the support stands. Both of the stands will have pressure sensors on the corners, in order to test the pressure the cardboard will exert on them. Once the robotic arm starts pushing down on the sleeve for a certain distance, the sensors will pick up how much force will be exerted on them from the sleeve. The stronger the force the sleeve exerts on them, the sturdier the sleeve is assumed to be. Once the arm retracts, the pressure sensors will output the results to the PC. Before this process can be perfected, testing of threshold pressure will need to be done to set a standard for flexibility qualifications. The result of this test will qualify a sleeve for either re-usability or it will be removed from the system. This essential test will provide real life results for a test that is used in the industry.

IX. Funding

The funding of the project was not of a major issue. As mentioned previously, our client, DST Output, has greatly contributed in funding our project. The biggest expense of building the Arm was obtaining equipment needed for motion control. Our client deals with many electromechanical systems as well as they were able to provide us with some surplus equipment they were not using. They have provided us with the needed motors, drivers, PLC, and cables necessary. Other hardware needed to build the arm was obtained from personal budgets. Every group member was responsible for purchasing the materials needed for the system the group member was assigned to. After doing final calculations, we have concluded

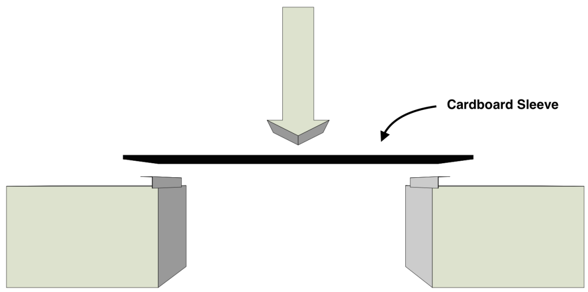


Fig. 11: Bending test [10].

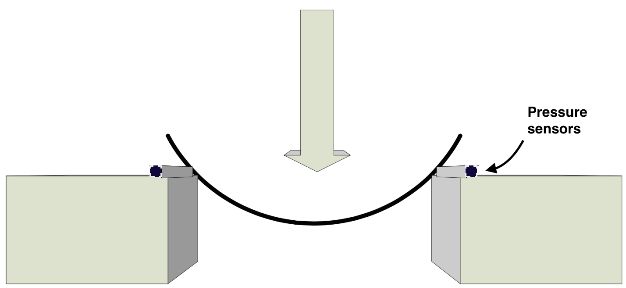


Fig. 12: Bending Test [10].

that each group member spent on average $100-$300, not including any tools purchased for future uses as well. In order to split costs equally, our group will sum up the costs and distribute it evenly among all the group members.

Our group was very blessed to have found a client which has provided us with the most costly materials and saved us much finances. We give our special thanks to DST Output.

X. Project Schedule and Milestones

A. Project Schedule

In the initial stages of the project we have made a rough schedule and set deadlines we should meet within our responsibilities. As a group, we moved along our schedule and did not have many set backs. See the table below which includes our schedule with approximate completion dates for each of the features of our project.

Project A.R.M. - Test Timeline

	Test Name (Task)	Test Type	Tester	Approx Date	Comments
Vacuum System					
✔	**Maximum Lifting Capacitance**	Mechanical	Igor Pishtoy	**2/20/2016**	**More Than Enough**
✔	Vertical Lift				~5-10 lbs (depends on surface)
✔	Horizontal Lift				~15-20 lbs (depends on surface)
✔	**System Response Time**	Mechanical	Igor Pishtoy	**2/20/2016**	**Improved Time**
✔	Grip Time				Less than a second
✔	Release Time				~0.5 ms
✔	**Other Tests**	Pneumatic	Igor Pishtoy	**2/13/2016**	**Resolved The Air Leakage**
✔	Varied Valve Pressure				Changed to a Vacuum Pump
✔	Air Leakage				Valve leaked at 45 PSI and above
✔	Valve Circuit				Exchanged to a new valve
Robotic Arm					
✔	**End-Effector Workspace**				**Complete**
✔	Reach	Visual	Aaron Sotelo	**2/15/2016**	We have an effective reach of 4.5 feet
✔	**Gearbox**				**Complete**
✔	Gear Ratio validation	Visual	Aaron Sotelo	**3/1/2016**	Gear ratios match calculated values
✔	Operation	Visual	Aaron Sotelo	**3/5/2016**	Gear boxes work well.
✔	**Standing Stabilty**				**Complete**
✓	Holding Stability	Visual	Aaron Sotelo	**3/18/2016**	Found an issue which affects stability.
✘	Stopping Stability	visual	Aaron Sotelo & Sergey	**3/18/2016**	Need to fix holding stability issue
Vision System					
✔	**Detection of Target**	Vision\code	Joseph Gonzalez & Igor	**2/29/2016**	**Complete**
✔	Orientation Testing\ Skew Testing				
✔	Exhaustive Sample Testing				
✔	Environment Lighting				
✔	**Target Pickup Location**	Vision\Code	Joseph Gonzalez & Igor	**3/7/2016**	**Complete**
✔	Orientation Testing\ Skew Testing				
✔	Exhaustive Sample Testing				
✔	Environment Lighting				
✔	**Detection of Tears**	Vision\Code	Joseph Gonzalez & Igor	**3/28/2016**	**Complete, With negative results.**
✔	Orientation Testing\ Skew Testing				Satisfaction with results is around 60-70%.
✔	Exhaustive Sample Testing				Needs more testing for 80-90% satisfaction
Motion Control					
✓	**Accuracy**	Visual\Code	Sergey Selyuzhitskiy	**4/5/2016**	**Awaiting more tests**
✓	Path Planning				Awaiting more tests
⧗	Picking up Sleeve				Needs communication to Machine Vision
⧗	**Stability**	Visual\Code	Sergey Selyuzhitskiy	**3/29/2016**	**Awaiting more tests**
⧗	Oscillation of Arm after movements				Awaiting more tests
✓	**Speed**	Visual\Code	Sergey Selyuzhitskiy	**3/29/2016**	**Awaiting more tests**
✓	Speed of Arm movement				Awaiting more tests
✔	**4-Point Stress Test**	Visual\Code	Igor Pishtoy	**4/12/2016**	**Complete**
✔	Accuracy of analysis				Accuracy needs improvement in future

***KEY (the color corresponds to the text):**

COMPLETED ✔
MOSTLY COMPLETED ✓
INCOMPLETE ✘
NOT APPLICABLE AT THIS TIME ⧗

Some of the set backs we have encountered were either due to our lack of knowledge of mechanics or long response times from our supporting professional engineers. In the initial stages of our project, we have used many 3-D printed parts, such as gears. Lacking knowledge and experience in mechanics, it was a great difficulty for us to build a mechanically efficient arm. Inefficient mechanical design of the Arm had put much stress on the plastic gears and caused them to easily break. Printing a new gear would take about 20 hours.

Another set back was the long response times from our support groups. Our client as well as the vendor of our equipment have offered us technical support with the software used for motion control; however, any questions were to be asked through email and at times took days to get a response.

All of the group members focused on their areas of work and did not have much issues with incompletions. There may have been other set backs such as waiting on shipment of orders, or waiting on partners to finish their system in order for those who are dependent on them to start working with their own system. Overall the group worked efficiently to take care of those set backs and get back on track.

B. Milestones

Each of the group members have had their own milestones they have reached. Igor, responsible for the vacuum system as well as assisting others, reached a milestone when he had received the parts needed for the vacuum system, and was able to connect them together to make enough suction to pick up a cardboard sleeve.

One of Aaron's milestones is the completion of the gearboxes. Much of the Arm's design was dependent on the gear design, therefore it was crucial to finish the gearboxes as soon as possible.

Joseph had a milestone when he was finally able to detect edges with his machine vision algorithm. It took quite some time in preparing the environment and testing different algorithms in order to finally get some results.

Serge's milestone was when he finally got one motor to work. Learning to use the vendor's software, configuring the PLC and the drivers for the motors, was also quite a challenge. Once the motors were configured, more testing could be done on the motion control.

XI. Project Work Breakdown Structure

Properly organizing and distributing the workload amongst our team members was the beginning of our project management. The workflow was broken down into the main features our project possesses, then the tasks those features have, and the sub-tasks those tasks address. This workflow can be seen below, starting from features such as: the robotic arm itself, our vision system, path finding or bin-picking, the vacuum system, and the communication between all of our systems. This paper also reveals in detail, the key understandings of how our robot will differentiate between a cardboard that can be reused again and a cardboard that needs to be recycled. Equipped with a visual inspection system, our robotic arm will achieve our solution via machine vision, which will be used to perfect the process of separating the reusable from the non-reusable cardboard sleeves. A properly designed vacuum system will be the main pneumatic system for lifting and releasing our cardboard sleeves. After the design of the separate systems, this paper reveals how all of our systems will be integrated to create a final product. Our final product will execute through a series of tests with our client, DST Output, which is also the examiner of our finished product. The workflow has been distributed as follows:

1) Robotic Arm (Aaron)
   a) 3-D Printed Parts
   b) PLC & Motor Modules
   c) Mechanical Parts
   d) Base
   e) End Effector
2) Vision System (Joseph)
   a) Cardboard Sleeve Recognition
   b) First Integrity check
   c) Secondary Integrity check
3) Path Finding / Bin-Picking (Sergey)
   a) B&R Automation Software
   b) Communication
4) Vacuum System (Igor)
   a) Vacuum Components
   b) Suction Cups
5) Communication Between Systems (Sergey and Joseph)
   a) PLC & PC Integration(System Integration)
6) Cardboard Integrity Test (Igor)
   a) Installation
   b) Pressure Sensors

A. Vision System

1) Cardboard Sleeve Recognition: The First major component of this task would be to visually recognize cardboard from a set distance. This task will involve dynamic analysis of multiple images taken to be able to correctly identify the shape of a cardboard sleeve. In this process the arm will extend toward the pallet that contains the cardboard sleeves and that is when the first task of this feature will be executed. After extending, the camera mounted at the end of the articulating arm will capture multiple images to send to the personal computer (PC) for processing. During processing the images will be analyzed to recognize the edges of the existing cardboard sleeves. Then the coordinate locations of all the cardboard sleeves in the frame will be saved by the PC. These coordinates will then be supplied to the programming logic controller (PLC), which then will make decisions on what to do with that list of coordinates.The estimated amount of time in order to complete this task is somewhere in the range of 15-20 hours. This time range is including the amount of time to setup software environments and to design the modular code. Another expected issue during this task that may arise is the issue of pre-filtering noise. In order to properly detect edges with the threshold we desire, we must pre-filter pixels that are undesired, which may add approximately 5 hours.

2) First Integrity Check: After detecting the object to be picked up, the next step would be to analyze the quality of the object. This will be known as the first integrity check. This subtask will consist of the same camera used in the first edge detection subtask. During this process the camera will be positioned above the first object to be checked and it will then capture an image of the cardboard and test it against a template of a predefined cardboard image in the PC. Based upon the resultant data, a decision will be made to either disregard the cardboard or bring it further into its process.

In order to complete this sub-task we expect many different test cases that will point to many different conclusions. All of the conclusions drawn from this assessment must be weighed by their importance and need. This assessment of all attributes will need to be thoroughly tested many times, to be able to create a reliable template of what a reusable piece of cardboard should be. The majority of the time will be spent deciding on a set standard for the target object. So in conclusion we expect to spend somewhere around 40 - 50 hours.

B. Second Integrity Check

This second integrity check will only be activated if the first integrity check passes the threshold of what is considered to be a viable target. During the first integrity check, only 2 faces of the cardboard will be examined, which will allow the other 2 faces of the object to be examined. In order for all visual inspections to be completed, this task must be completed as well. The basic criteria to be checked in this integrity inspection will be very similar to that of the first integrity check.

All together we expect this sub-task of integrity checking to take somewhere near 15 - 20 hours of work. Only the secondary base camera will be used during this process and the same materials needed for the first integrity check will be used again.

C. Robotic Arm

The robotic arm feature of this project is the main feature by which locomotion and manipulation is achieved. The arm is made of many parts, some of which are 3-D printed, and others which are made of metal. The driver behind this design is the need to be able to move vertically by varying degrees and to have a reach that allows us to manipulate objects freely. The total time estimated for the completion of this task would be 20 to 30 hours, since this integration will combine multiple pre-made and custom-made parts, that may need to be redesigned. The materials needed for this task will involve multiple square feet of metal tubes, metal plates, motors, and a PLC.

D. Path Finding / Bin Picking

Path finding and bin-picking might be the most challenging parts of this project.The act of bin-picking can be boiled down to having a bin of objects and picking one from the bin, and moving it to a desired location. This is a challenge for robotic systems because the objects in a bin can be in an ordered orientation, or in a random orientation. Path finding relates to the calculation done in order to properly coordinate the motors for the end defector to reach the required position. For these purposes we will be using the B&R's software Automation Studio 4. Approximate time for implementation: 100-120 hours.

1) B&R Automation Software: B&R Automation Studio 4 is a great application which will be available to us. It has many great features which will help us to interconnect all of the electrical components. One great feature included in this software is the compatibility with higher level language such as ANSI C [38], language which we are comfortably familiar with. Programming the drivers in a known to us language will save us much time.

Another great feature of the Automation Studio which will help us with path planning is the IEC 61131-3 PLCopen motion control blocks [38]. With minimal programming, this feature will use a path generator to calculate all setpoints for each motor's axis. Our task is to properly configure it and put enough time into testing it. Approximate time it will take to implement this feature is estimated at around 80-100 hours.

2) Communication: Bin-picking is another feature which might take a considerable amount of time to implement. This feature will require the task of establishing proper communication between the PLC and the PC. In order for the PLC to start calculating the path to the cardboard sleeve, it needs to get accurate information on the target location on the face of the cardboard sleeve, as well as the target's orientation. Using features such as machine vision, the PC should be able to calculate the position and orientation of the target and communicate the data to the PLC. The PLC will analyze the received data and use path planning in order to find the shortest, most efficient path to the target location. The approximate time to implement and establish proper communication is estimated at around 20 hours.

E. Vacuum Components

The vacuum system of our robotic arm consists of the following components: suction cups, vacuum switches or regulators, vacuum generators, and other optional accessories that make up our system.

Since none of the tasks above require actual physical construction of the pieces, the primary factor that will affect our time is the purchasing of the components and assembling them. As always with our new technology, troubleshooting might be required from time to time, which will be an additional amount of time to our total time. The approximate hours of labor required for the vacuum system can range from 5-10 hours, excluding the integration with the robotic arm.

XII. Risk Assessment and Mitigation

The risks of our robotic system were organized into four sections, with each section showing an analysis of the risk and the mitigation strategy for dealing with the risk. Our vision system has a risk of detecting false objects and not correctly analyzing the quality of our cardboard sleeve, based on our threshold. The vacuum system has a risk of damaging the product, having insufficient lifting power, and reduced performance because of clogs, hose length, and other factors. The motion control mechanism has a risk of producing instability and inaccuracy for the arm's movements, and has a potential risk of damaging the motors. The robotic arm itself has a few risks to bare in mind, such as: risk of 3-D printed parts either too weak or printed incorrectly, machined parts take a long time to cut, and the risk of the arm structure being too heavy for the other components. The chart below depicts our risk assessment of each section:

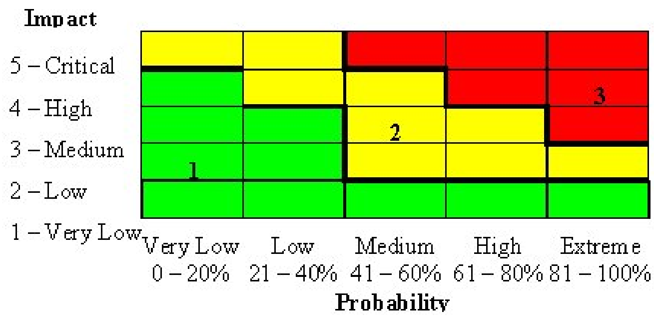


Fig. 13: Risk Assessment Chart [11].

1) Vision System Risk
   - False Detection: **Medium, 4**
   - False Quality Assurance: **Medium, 4**
2) Vacuum System Risk
   - Damage to Product: **Very Low, 1**
   - Insufficient Lifting Capacitance: **Low, 2**
   - Reduced Performance: **Low, 2**
3) Motion Control Risk
   - Instability of Arm: **Low, 4**
   - Inaccuracy of Arm: **Medium, 5**
   - Damage of Motors: **Low, 5**
4) Robotic Arm Risk
   - 3D Printed parts:**Medium, 5**
   - Machined parts:**Medium, 5**
   - Weight:**Low, 5**

A. Vision System Risk

1) False Detection: When designing our vision system we need to correctly identify all potential objects that will be graded for their quality. In our design we are placing the system to make its initial route based on what pieces of cardboard exist in the scene. The scene that the camera will be examining is the top view of a pallet. This pallet will have multiple stacks of cardboard sleeves placed upon it.

The interesting issue that comes about when trying to interpret the image of the pallet is "How do we process that image?" There are many ways to go about this with the machine vision language we are using. To shed some light on the subject matter there are multiple algorithms and techniques that can accomplish similar goals. Most of these techniques require that an image be filtered first and this involves removing unwanted pixels that will provide extra overhead in processing. The second step is to either highlight the features that we want to process or to use what is called a feature detector [39] and define the image's features based on a mask while saving all the features to a matrix. This step has the most variance with respect to execution time and the actual output result. There are many different types of algorithms created to detect features and each one of those algorithms has a different speed at which it can process with respect to its parameters. An example of the Surf Detector [12] can be seen in Figure 14. The third step

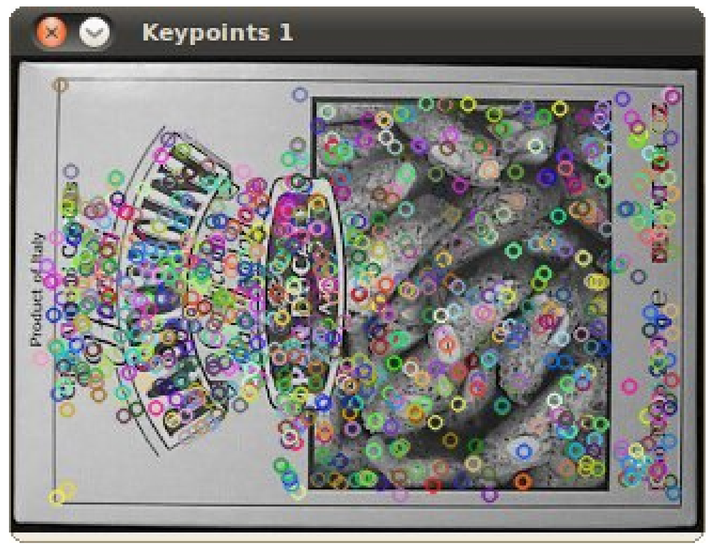


Fig. 14: Example of Features being defined by the "Surf" algorithm [12].

is to use a feature detector on our library of images we wish to find, this is how we can define our object. Once we have two separate matrices of key points, we can then use a matcher to see how similar the images are. This is were an object can be found and is our step three. Step four involves defining a correct threshold to alert the program that we have found an object. The last step is to take those correctly matched inputs and use a technique that identifies the edges of the area that contains those matches and draws the shape to our screen, in our case a box. Each one of these steps can be done in many different fashions and with many different parameters to define how the algorithm should work. This in turn creates a much more variant process. If we do not choose the correct approaches to any of the sub steps that are presented above we will not be able to correctly define our objects.

The steps that need to be performed are not finite therefore it grants this project plenty of freedom and flexibility. The downside of this is that there are a plethora of combinations that define each step. Not choosing the correct way to perform our steps could cause us to either not detect a cardboard properly or not detect a cardboard sleeve at all. Our system needs to correctly identify a single cardboard box correctly the first time without any possible problems. The reason we can not afford to misidentify is because we need to articulate our system and test our cardboard's integrity. The system will waste an entire trip which potentially would cost our system somewhere in the neighborhood of about 20-40 seconds. This becomes an unnecessary misstep that creates a gap in the production process. The likelihood of this type of issue of not being able to properly detect a single sleeve creates a very high resultant impact on the system's execution. The probability of this happening is very high if the incorrect steps are taken. We have done a large amount of testing and believe we have already mitigated a large part of the probability thus lowering the probability to around medium. At this point in time we are testing many different variation of techniques and believe we can lower this probability to very low by the end of the semester. The reason we continue to test and probe our quality of technique is to keep our system in a continual process of lowering high impact debilitating outcomes.

2) False Quality Assurance: When checking the quality of the material that is under inspection we use the same type of image processing used in our object detection. While the processes are very similar there are significant differences. The process involves a much more granular look at the cardboard. The images being processed will need to be filtered in different stages to make sure we are finding all possible problems. This process is much more comprehensive and will have very severe consequences if not done correctly.

The are multiple steps or stages to this image processing. After the objects in the scene are recognized the arm will articulate to the location of the first box in question. It will then take a scan of the cardboard and filter the image to remove any other objects that we do not need(noise). After this is done we then check the images against a series of pictures that contain known defects such as holes and tears. To do this we will need to use a feature detector as described in the section before this that is scaling invariant. This way we can use less photos to detect an assortments of tears. It is imperative to detect any defect that could potential cause the system to fail. This is why we have evaluated the outcome of severity to be quite high. If we evaluate a bad piece of cardboard to be a stable one and enter it back into the conveyor system it could cause a stall on the production floor. This defeats the purpose of our system and its goals of removing unqualified pieces of cardboard. The probability of this issue arising is high but we are taking precautions and doing major amounts of testing in the object detection phase to be able to mitigate some of the risk down to a medium amount of risk. If the object detection phase's probability of successful outcomes increases the quality assurance phase's probability of success will also increase because most of the algorithms will build off each other.

We believe that the quality assurance's risk is quite low if we can properly mitigate all of the risk taken in the first object detection phase. This is due to the similarity of the feature detectors that will be used. Most of the code used for object detection will be leveraged in order to suit the new needs of the quality assurance. One of the major points that needs to be addressed during the transition of code will be threshold testing. Every step in the image processing requires a light touch to adjust thresholding between different types of point matching, this is a time consuming process but necessary to accomplish our goal.

To properly mitigate the risks here means that we need to properly mitigate the issues purposed in the first object detection phase. We believe that planning a fast and accurate method of detecting the objects in the initial phase will ensure that the other phases will produce reliable outcomes. Our plan for mitigation that we are currently using is to test many different combination of algorithms. This involved finding and testing many different feature detector and many different ways of matching those features. Other techniques involved testing multiple filtering stages to try and eliminate noise from our scenes to provide faster scaling and transformations. While finding and testing different combinations is very time consuming, we have found it to be very enlightening and it has already began to pay back. At the current moment most of our risk pertains to cpu overhead and finding reliable thresholds. Overall continually testing code and looking for possible issues before they pose a serious risk gives our project an every changing mitigation plan. Our vision system's mitigation plan is to test very consistently when there are and are not any issues.

B. Vacuum System Risk

The design of the vacuum system is a crucial component of our robotic system because it is the primary mechanism for lifting the actual product. It is the mechanism that holds our cardboard with considerable stability and caution. Since this system plays a key role in our robotic system, a few major potential risks arise. The assessed risks that can potentially produce a delay or uncertainty in our final implementation of the vacuum system are as follows: damage to the cardboard, insufficient lifting capacitance, and reduced performance. Each section is discussed in fair detail and is logical and consistent to the actual risk. One must be aware that all the risks of our vacuum system cannot be addressed due to the fact that they're either insignificant or have minimal impact.

1) Damage to the Product: For a robotic system equipped with a vacuum system, the quality of the product is an essential aspect, which is usually highly important to a consumer. Since our product, a cardboard sleeve, is a porous material and not the most sturdy material, it has a potential risk of being damaged. Careless lifting of the cardboard can easily damage the cardboard sleeve to such an extent that it has a potential risk of not being used at all. Since our goal is to preserve the cardboard sleeves that are within a certain ”passing threshold” (see glossary for an explanation), what good will it do if our vacuum system's end-effector damages the product?

Also, our vacuum system has the capability of supplying powerful feed pressure. A high feed pressure is capable of ripping a piece of the cardboard material per area of a suction cup, or leaving marks on the cardboard if proper pressure limits are not set. The picture below displays how suction cups can leave a mark on a piece of cardboard. Imagine our robotic arm grasping the cardboard material with its two suction cups and lifting it, only to see two holes in the cardboard sleeve and two circles clasped by the suction cups. Therefore a reliable feed pressure is needed to completely rid ourselves of this risk.

Fig. 15: Marks left by suction cups. Note: not to scale & the color yellow was used to show a clear distinction [13].

Since damage to the cardboard sleeve by the vacuum system's feed pressure is a potential risk, our mitigation plan completely reduces this risk to a system with the ability of leaving no damage. Our strategy consisted of mostly tests and precise calculations, as well as research pertaining to the design of suction cups specifically for our project. The chosen suction cups were tested with our working vacuum system, to only witness positive results and absolutely no damage to the cardboard sleeves.

2) Insufficient Lifting Capacitance: Although pneumatic systems tend to clog, there are many ways to reduce clogs and extend the life of a pneumatic system before it needs cleaning. Our vacuum system is obviously not prone to this type of risk as well. The reason why clogging is a risk is a no-brainer. High pressurized air flowing through pneumatic tubes is not only air, but dust particles, tiny parts of your skin cells, and other microscopic things related to pollution. This is the primary reason for the invention of filters, such as filters in your vehicle's intake system, a vacuum cleaner filter, or even the small hairs in your nose! Such disturbances can cause our vacuum system insufficient lifting capacitance.

Another annoyance of any pneumatic system is air leakage, which also causes pressure drops. If you ever had to deal with a system leaking air and the task of finding the air leakage, then you probably understand that it is usually not an easy task without the proper tools. Since our vacuum system is connected with various sizes of brass adaptors, they are capable of leaking pressured air because of two primary reasons. First, the air is under high pressure and is forced to find openings, if they exist. Secondly, if the adaptors are not tightened or sealed properly, then the first reason is the cause of air leakage.

Fig. 16: Example of water leakage, but if water can leak through an adaptor, air will definitely leak [14].

The picture above depicts a clear example of how an air leakage can occur in our vacuum system. Air leakage in our system could potentially provide insufficient lifting power for the suction cups, making our system unreliable.

Risks such as air leakage and clogs are risks that can easily be avoided if applying the correct mitigation plan. Without analyzing and addressing this risk, our system has the potential of being inefficient and error-prone, as well as not having enough power to lift a cardboard sleeve. Our mitigation plan consists of using filters and a manual monitoring system for clogs or air leakage. Another technique for battling air leakage is using teflon tape where possible air leakage may occur. Therefore, our system is also secured from this type of risk. In the future, if time permits, we would gladly upgrade our monitoring system to an automatic electronic system with gauges or a remotely setup environment.

3) Reduced Performance: Performance is a vital checkpoint for any robotic system. The risk of not addressing performance risks of our vacuum system is a failure to examine a major goal of many robotic applications. Speed and accuracy is one of the major goals our client, DST Output, is concerned with. For our vacuum system, the length of the pneumatic hose can be a decisive factor for the performance of our robot's ability to lift and release the cardboard sleeve. The risk here is having unnecessary hose volume. Joseph Karbassi, a vice president for automation division, claims that ”the most effective system is where vacuum is generated as close to the suction cups as possible” [40]. This statement by Karbassi can be examined with logic as follows: if the vacuum hose is longer in length, the longer it will take for the pressurized air to arrive at the suction cups, but if the vacuum hose is shorter, then the air will reach its destination faster, assuming the pressure is equally applied in both tests. Therefore the length of a vacuum hose plays a significant role on the performance of the overall vacuum system. Our chosen hose length was twenty-five feet because of shorter hoses were more expensive and hoses too long would provide more pressure drops along the length of the hose. Avoiding as much potential risk as we can, we chose our vacuum hose and our resulting tests with this hose were only positive. Therefore, this risk was reduced to a minimal impact.

To conclude the risks of our vacuum system, we state with certainty that our vacuum system is reliable and efficient. Not only does our vacuum system has enough lifting power, but also handles our cardboard with caution and quality. Although there are faster systems available for in robotics, our vacuum system is the most appropriate design for our project, which can be considered as an overall risk for our entire vacuum system. This overall risk is unavoidable, since we had to make a judgemental decision when deciding upon what type of lifting system our robot will be equipped with.

C. Robotic Arm Risk

The physical construction the arm produces an independent set of risk that could delay the implementation and increase the cost. There are 2 main areas from which the risk comes from. The first is construction of the parts and the second is the properties of the parts themselves. The first set of parts that produce a medium level of risk are the 3D printed parts.

1) 3D Printed parts: The production of 3D printed parts is rife with various causes of error. The errors can come form mis-leveled beds, to expired PLA, and even from a drafty room. For our design we need to print multiple 10 hour parts and various 20+ hour gears. This exposes our project to enormous amount of risk since the chance of a print failing increases as the time to print increases. To mitigate some of these risk Aaron has volunteered to use his own printer to produce these parts. This allows the mitigation of some of the risks. The PLA used to produce these parts can now be verified that it has not expired. As well as the use of a third party monitoring software to monitor the progress of the prints. The risk that is still present however is just the common risks involved in 3D printing. They can all be mitigated by following a standardized procedure.

The procedure in question is derived from experience in working with our in house printer. The procedure begins by prepping our print surface by removing the old painter's tape and replacing it with a new layer. The next step in this procedure is to apply a layer of hairspray to the surface. This step is not mandatory but it aides in adhesion of our filament to the print surface. The next step is to verify that our print bed is level. We do this by using a sheet of paper to determine the correct spacing between the print head and the print surface. After this we can begin printing, but have to mo niter for the first 15 minutes to verify that our print is proceeding without issues.

Even after following this procedure we may still get some defects in our prints. As seen in figure 17

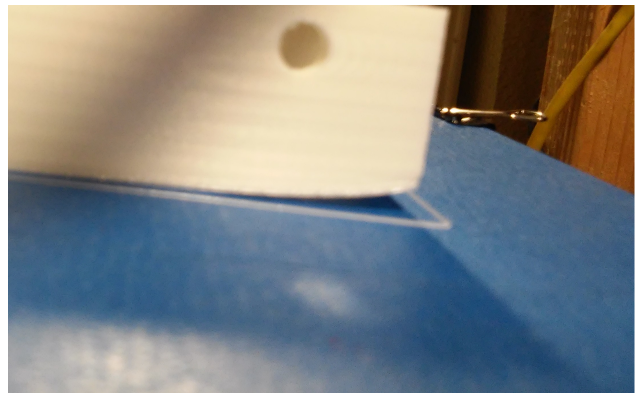


Fig. 17: Potential Print issue [15].

These types of defects don't affect that particular part, but if we fail to get good adhesion on the gears we could run into trouble because our gears will be warped. Once again the most critical part of avoiding this issue on our gears is to follow the print surface prep procedure. These types of risk are common in manufacturing parts for a project, and as such are also present in the non-printed parts.

2) Machined Parts: The risk in having metal parts is that we have few tools to machine the necessary parts. For example we can cut our aluminum tube to length, but in order to get the precision needed to function properly we need the holes to be drilled with a drill press as they have to go straight through the tube. The risk in this part of the project comes from delays in both getting designs to the Mechanical workshop, and the turn around time for the parts. This also introduces the potential of the workshop making an error.

The mitigation strategy we implemented for these risks, is to confirm our designs and then submit them as soon as possible to get an estimated time-line on when we could get the parts back. Once the parts are once again in our possession we would verify they match with what was turned in. The only thing our mitigation strategy does not handle is the turnaround time for the workshop, although we can ask about the expected delivery date and then determine whether or not we can manufacture the part or parts ourselves on a faster time-line.

3) Weight: The last major area of risk for the physical construction is the total weight of the arm. The weight of the arm is a critical aspect of its construction. The weight determines various aspects of our robotic manipulator, mainly the gear ratios and the maximum speed at which it can move. This can also give us problems when dealing with the motors. If the weight is to high we will need higher gear ratios.

The mitigation strategy for dealing with this area of risk is to use the lightest materials possible. The metal and non-printed parts are to be made from aluminum. We can go further this by making the struts that hold our arm together out of aluminum. Another strategy would be to drill out holes in our aluminum. This would allow us reduce some minimal amount of weight. One last strategy would be to modify where our motors are being placed. by shifting the motors on the arm one place in, and using belts to drive gears we could reduce some of our gear ratios. This is better explained in figure 18.

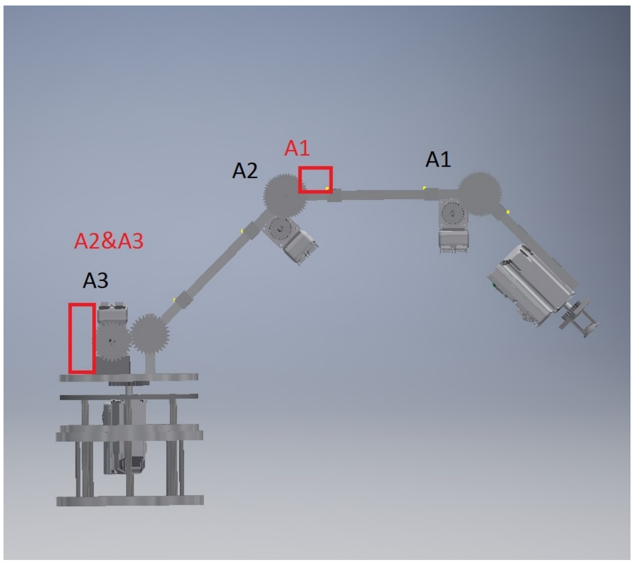


Fig. 18: Motor Strategy [16].

As seen in figure 18 the original placement of the motors is shown in black lettering. The potential mitigation strategy, would put the motors at the proposed locations in red.This strategy would add some complexity but would reduce our required gear ratios by a little bit. This strategy would introduce the issues related to belts but would also help reduce the total weight of the arm by moving at least one motor off the arm assembly an onto the base.

For the final strategy of mitigation, we ended up removing some motors due to them just being to heavy for the arm. This resulted in many changes to the robot, such as the addition of counterbalance springs, which aid in reducing the amount of torque, that needs to be produced by the motors. This is visible in figure 8. Here we can see that the springs serve to reduce the torque by pulling on the arms. The inspiration came from looking at cranes and researching how they combat large torque loads.

D. Motion Control Risk

Dealing with electromechanical systems, there are many risks involved which cannot be neglected. Improper configuration or inaccurate calculations in systems like ours, may cause damage to equipment, inaccurate results, and even injury. It is very cruicial to mind all the risks involved in building the system and having a plan for mitigation of the risks.

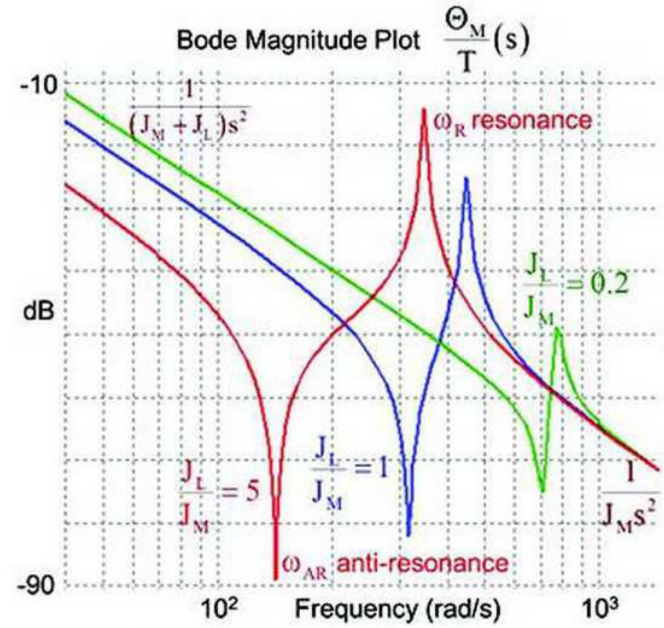


Fig. 19: Impact of Different Motor/Load Inertia Ratios [17].

1) Instability: In electromechanical control systems such as the one we are designing, it is very crucial to mind the inertia of the load. While as the sufficient torque may easily be calculated in order to be able to handle the load, it is also as important to mind the stability of the system. One risk that some engineers face is not minding the inertia of the load. In order for the system to be stable, it is recommended to have a very low load-to-motor inertia ratio. For the system we are designing, a professional has told us that ratio is recommended not to exceed 10:1. When the ratio exceeds the recommended ratio, the system becomes very unstable, and may lead to inaccuracies as well as damage to equipment. In the figure above, we could see that the lower the load-to-motor ratio is, the lower the magnitude of resonance is. When the arm itself accelerates and then is rapidly stopped, the energy needs to go somewhere. In many cases when the inertia ratios are neglected, the arm may start oscillating, the motor might slip a couple more gears, or some parts of the arm might even break. In our situation, we have not yet put the system together, and we have the ability to calculate first the inertia ratios. Using the motors which we will be provided, we may calculate the gear reduction needed in order to minimize the inertia ratios for maximum efficiency. The risk lies in our very small knowledge of mechanical engineering concepts. Most of our group have taken physics at least a couple years ago and we have much to learn in order to properly calculate the ratios. The risk lies in the chances that we may make some miscalculations.

In order to minimize the risk, we are in need to some good resources which could help us with the calculations. We are in need of a mechanical engineer or a physicist who could help us calculate or verify our calculations to let us know if we are on the right track.

Searching through CSUS resources, we were able to find a tutoring center in the physics department which could help us with some calculations as well as many concepts in physics. We have also access to some mechanical engineers on CSUS campus with whom we could meet for consultation. Our sponsor, DST Output, also has some mechanical engineers in the company who could verify our calculations and help us out to avoid this risk.

2) Inaccuracy: Working on a project such as a robotic arm which will be picking up objects, it is important to put much focus on the accuracy of the arms positioning. The robotic arm will need to accurately position itself, (using the drivers to properly manage the power to each motor), in order to get to the exact position required to pick up the load. There are a couple of risks involved which will affect our accuracy. One risk lies within our ability to properly configure and program the drivers which will be powering the motors to properly position the arm. The second factor to our accuracy is the input from the Machine Vision, which will provide the PLC with precise coordinates as to where the cardboard is located.

As students, we have not had much experience yet working hands on complex systems as such. The professional equipment which we are given, along with professional software for configuration, may require much time to study in order to be able to properly and efficiently put it to use. With improper configuration, or improper input from the Machine Vision, if the robotic arm will grab the cardboard 2 away from the desired location, one of the suction cups might easily miss the cardboard or try to grab it on the side, and the whole system will fail.

The likeliness of us misconfiguring the drivers or the Machine Vision depends on the time and resources we have to learn about the equipment. Time is not much of an issue as resources. Looking through online resources, we were not able to find much support for the professional software we will be using to configure the drivers.

Therefore, we need more resources which could help us learn how to properly configure the motors. Such resources include engineers who have worked on electromechanical systems using this software, who could help us and guide us.

We have found such engineers at the vendor of the software and the motors/drivers. After communicating them our need, they have agreed to help us with any issues we might have with their software, and will provide all support which is necessary for us to achieve our goal of building a successful, efficient, cardboard sorting robotic arm. We have also found a fellow student in our university who is in the graduate program and has much experience with Machine Vision. He is also open to us for any consultation.

3) Physical Damage: Another risk we are facing is damaged equipment. Many of our parts may break if used incorrectly. The motors we will be using can produce much torque, and therefore we need to be very careful configuring them and installing them. Installing the motors incorrectly may cause damage to the gear system or the motors. The motors were very costly and we need to take very careful measures in order to minimize the risk of damaging them. Our motor supply is very limited, and if one of the motors breaks, it will be very costly and time consuming to replace it. A new motor may cost in the range of $500-800, and they will be shipped from Austria which will take over a week to receive it. Other parts which might break are the 3D printed gears which will be connected to the motors. Aluminum pieces holding the robot may also bend with enough force. In order to decrease our chances of damaging equipment, certain precautionary steps must follow.

One obvious step we must take in mitigating the risk of damaging equipment is to set safe working zones and to put safety locks to prevent any pieces such as an arm going past its safety zone. Another obvious step is to recheck and recalculate all of our work to make sure we did configured everything properly, and to let a professional engineer look and verify our data before doing any physical testing.

XIII. Other Design Documentation

There were no other design issues not covered elsewhere in the report.

XIV. Conclusion

With the vast amount of research performed for this problem, our team concluded that our robotic arm is useful in many cases, as well as in the case of reusing cardboard sleeves as many times as they are capable of being used, which yields a more efficient recycling system and reduces the consumption of forest resources. Reiterating our solution, this approach reduces the environmental impact of the cardboard by completely removing the energy, chemicals, and resources needed for the recycling process, and therefore will benefit our society, as well as potential consumers.

The robotic arm consists of many features and tasks, which required much time for implementation. The arm consists of systems such as the vision system, path finding, vacuum system, communications system, cardboard test, and the mechanical assembly. Each of the systems is essential to our design and required careful planning and set up. In order to accurately plan the workload, we had to break it down into many tasks and sub-tasks. Minding every task and sub-task which needs to be worked on, we are able to manage number of hours and materials needed to produce the desired result.

Complex electromechanical projects such as our robotic arm, require large amounts of testing for every single system. Every system including the vacuum system, motion control, physical structure, and the machine vision needed to be tested to find its limits and weaknesses. Also, there are many risks involved in building electromechanical systems. Our duty as engineers was to mind all the risks and take steps to minimize them as much as possible. Having a plan for risk mitigation increased our success rate while assembling our robotic arm.

Thus, our robotic arm should help increase the re-usage of corrugated cardboard. With cost-effective and reliable solutions, companies will be able to reuse much more of their cardboard and decrease the amount of cardboard they recycle.

Our prototype can help many companies which use cardboard sleeves for mail. With efficient sorting of the cardboard sleeves, many more companies may be interested in this cost-effective solution. Helping many smaller businesses grow by saving them finances on manual labor certainly adds up to the benefit of saving more energy by lessening the recycling of cardboard.

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XV. GLOSSARY

Robotic System: A system of components composed of robotic pieces, related to mechanical engineering.
Path Finding/Bin Picking: The planning related to finding the shortest distance between two points.
DST Output: American software development firm that specializes in information processing and management.
BSD: Berkeley Software Distribution.
PC: Personal Computer.
Script: A program written for a special run-time environment.
PLC: Programmable Logic Controller.
Acrylonitrile butadiene styrene (ABS): is a common thermoplastic polymer.
Polylactic acid (PLA): a biodegradable thermoplastic aliphatic polyester derived from renewable resources, such as corn starch (in the United States and Canada), tapioca roots, chips or starch (mostly in Asia), or sugarcane (in the rest of the world).
Image Processing: Related to Vision System. The analysis and manipulation of a digitized image, especially in order to gain data.
Modular code: The process of breaking a logical program into smaller more comprehensible segments.
OpenCV: Open Computer Vision, an open sourced software library used for image processing.
Open Source: denoting software for which the original source code is made freely available and may be redistributed and

modified.
Vision System: synonym for machine vision, which is the technology and methods used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance in industry.
Vacuum System: a pneumatic system composed of an air compressor, a vacuum generator, tubes, adapters, valves, suction cups, and other pneumatic components.
Pneumatic: containing or operated by air or gas under pressure.
End-effector: Device at the end of a robotic arm, designed to interact with the environment.
Feed Pressure: pressure that is usually supplied from an air compressor (or something related) to an end-effector or to a component that is dependent on the pressure provided, such as our suction cups.
B&R: B&R Automation, the vendor of the motors, drivers, and PLC used in this project. *Note: the following definitions were obtained from our own contribution or Wikipedia [41].*

A. Appendix User Manual

1) Vacuum System The first prototyped Vacuum System consisted of a few components that are essential to its function (See Appendix B - High Level Overview of Vacuum System Figure). To use the Vacuum System, one has to make sure that all of the components of the system are attached properly, see Figure below for reference. Our first prototype of the vacuum system included: once all of the components are intact, the air compressor and the switch have to be plugged in to an outlet. Then we set the PSI of the air compressor at anything above 40, and turn the valve switch on, for suction. The simplicity of this system enables it to have an easy configuration, as you have witnessed above.
The final prototype consists of a simplified design. It consists of a vacuum pump, a 25 foot hose, the same solenoid valve, and the same suction cups. This design includes less brass pipe connections. See image below for the vacuum pump:

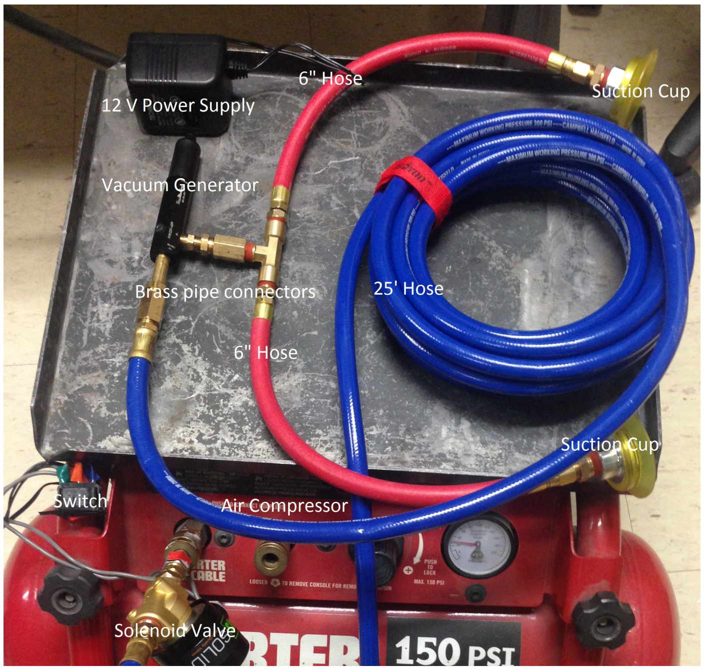


Fig. 20: Vacuum System Components [18].

2) Vision System The vision system does not require user interaction as the system as a whole is automated. In the view of a developer there are requirements and assumptions that must be made in order to contribute to or modify the current system. The requirements for initial detection of the target object (a cardboard sleeve) are few and simple. Firstly the object must be in clear sight of the camera's view. The object detector used in our software is designed to find the object at an optimal distance of around 1.5 ft to 2 ft. At this distance the box takes up 95 percent of the windowed view. The next requirement is the lighting. The lighting must be adequate and uniformly distributed amongst the object in a manner that causes no over exposure.

Fig. 21: Vacuum System Pump [19].

3) Motion Control System
The motion control system is automated and works as programmed. The PLC, once powered on, controls the motors by itself based on the cyclic.c file which is transferred to it from a local computer. Therefore, there is no manual input required to operate this system rather then just powering it on (plugging it into the outlet).

B. Appendix Hardware

1) Block Diagram
   a) Vacuum System
   The first prototyped Vacuum System was composed of a few simple parts that make up its system. Below is a Block Diagram displaying all of the components in a high level view:
   The final prototype Vacuum System is shown below:
   b) Vision System
   This system does not require a block diagram for the hardware because the setup is quite simple. The high level logic of the operation of the code will provide a better understanding of the task of this system. This can be seen below in Figure 24.
   c) Motion Control System
   So far we were able to successfully connect and control three motors. The motors are all connected to drivers, and the drivers are connected to a PLC (PowerPanel 420) via POWERLINK cables. See Figure 25 below for the diagram.
2) Schematics and Documentation to Component Level
   a) Vacuum System

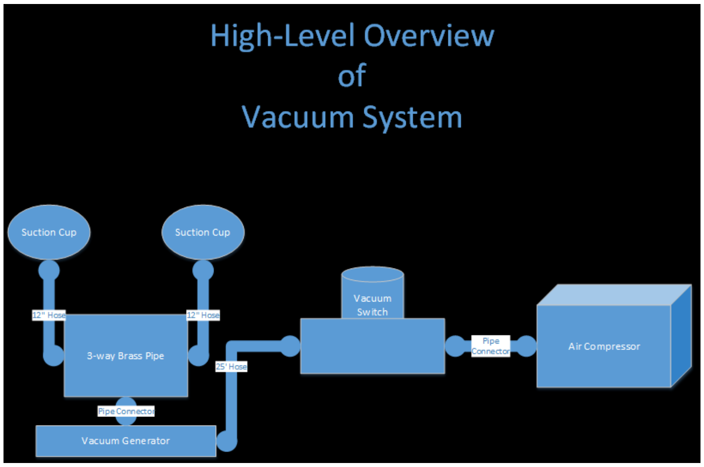


Fig. 22: High Level Overview of Vacuum System [20].

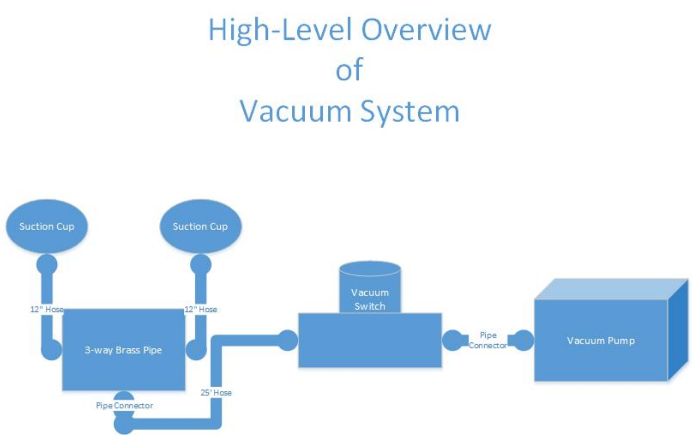


Fig. 23: Final High Level Overview of Vacuum System [20].

Currently, there is only one schematic for the Vacuum System, which was the switch for the solenoid valve. It is a simple circuit and one can quickly understand it by observing it below:

b) Robotic Arm
Reference images and diagrams are presented below near the end of the document.

c) Vision System There are only two 3 components to this system, the two camera and the computer running the vision software system. The simple diagram can be seen in Figure 27.

d) Motion Control System
The components that go into the motion control system include the B&R PowerPanel 420 (See Figure 28), which acts as our PLC; D100 B&R Drivers (See schematic in Figure 31); and B&R 8LVA motors (see Figure 30 for specifications). In Figure 29 you can see what our drivers and motors look like.

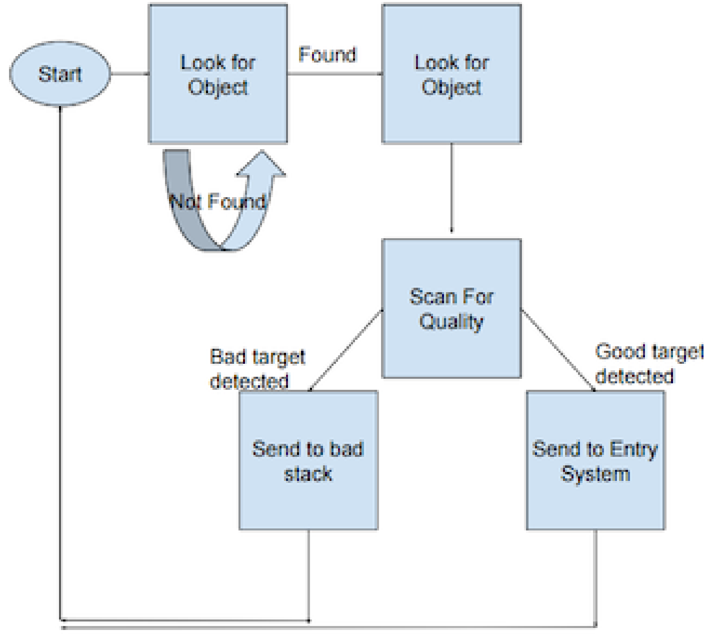


Fig. 24: High Level view of the Vision System [21].

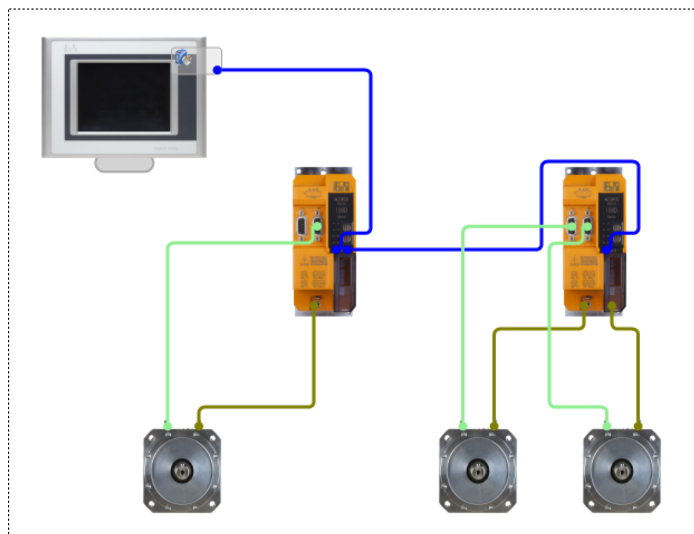


Fig. 25: Overview of Motion Control System [22].

3) Test Plan and Test Results for Hardware

a) Vacuum System The Vacuum System results were satisfying and as expected. To lift a cardboard sleeve with dents and rips was more difficult because it required a tight seal on the cardboard, which meant that more pressure had to be applied. Other than that, we were able to lift all of our cardboard sleeves.

b) Vision System When testing this system it was apparent that it needed a lot of attention when it

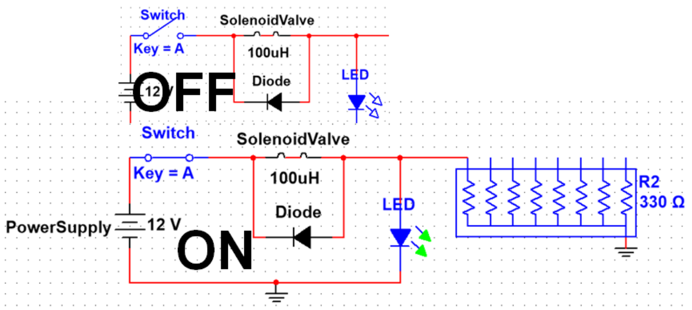


Fig. 26: Solenoid Valve Circuit [23].

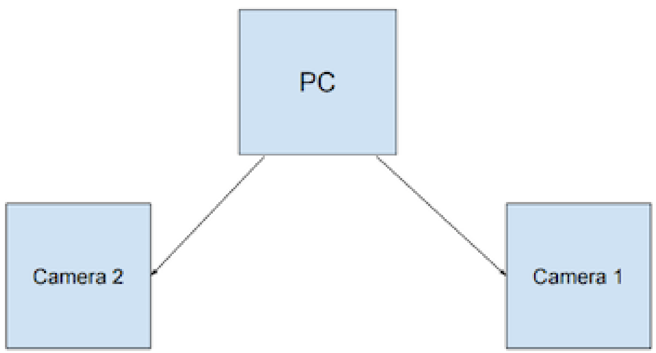


Fig. 27: Components of the Vision System [24].

came to parameter adjustment and library updating. The object detection bases its definition of the object by testing against a library of photos, this library had to be frequently updated and tested in order to ensure quality of the results. The hardware testing was not an issue for this system because the open source software is compatible with a wide array of hardware.

c) Motion Control System
We have tested the motors separately with just a bare shaft and were successful in making them follow a state machine rotating at which ever speeds we configure them in any direction. Testing them on the robotic arm however, appeared to be much more challenging due to the constant failures of our gear design. Once we will improve our gear design and overall mechanical design, we will be able to perform more tests of our motion control system.

C. Appendix Software

The focus of the software information relates to Motion Control and Machine Vision.

1) Machine Vision
The machine vision software used was the popular OpenCV [42] library. As discussed earlier and in

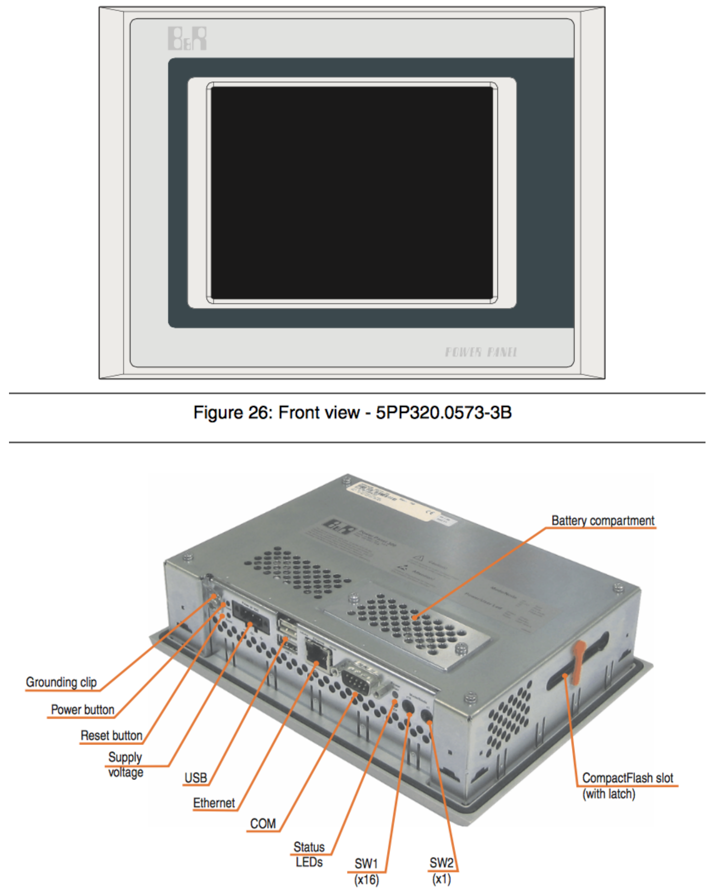


Fig. 28: Power Panel 420 Overview [25].

previous documents this system is open sourced and has a wide community. The object identification system is based on a scale-invariant feature detector. The feature detector currently being used is the ORB (Oriented FAST and Rotated BRIEF) [43], as opposed to other previous proprietary detectors. This feature detector works well for our target identification. The quality inspection being implemented uses this same basic feature detector to scan a library of photos.
Issues encountered during testing were frequent. To get successful results many trials had to be conducted in order to find correct scaling and filtering techniques. Techniques involved blurring images and filtering noise from the images. Although the feature detector is scale invariant the key-points detected in the image can only be distorted so much therefore threshold testing to find extremes was also undertaken. Finding extreme angles and filtering techniques helped us create a criteria for our object detector. Images of our tests can be seen above. Samples from our library can be seen in Figure 32, Figure 33.
Machine vision was time consuming due to vast amount

Fig. 29: Motion Components [26].

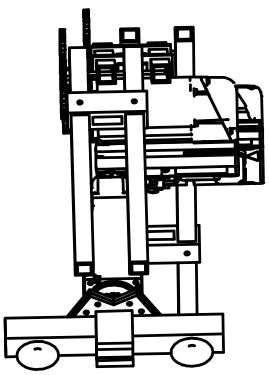
of techniques that could be used to complete this task. The task at hand was of the utmost importance because it is the entry for the object to begin quality inspection.

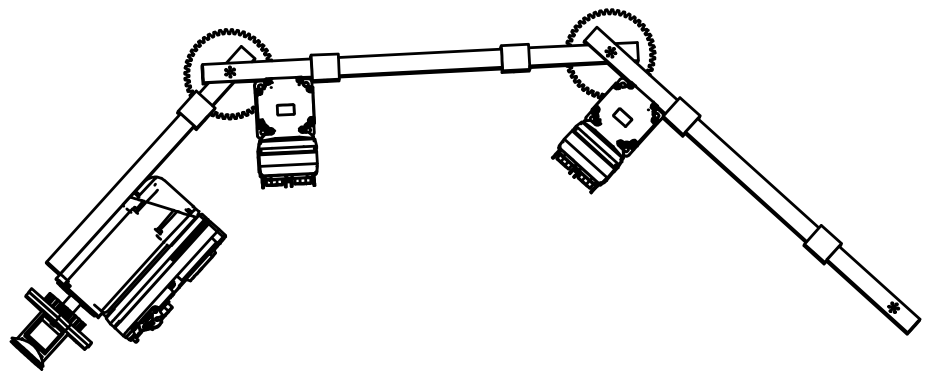
2) Motion Control
For programming the motion control, we have used B&R's software Automation Studio 4.2. Using this software, we have configured the motors and wrote a short program in cyclic.c and init.c files, which are transferred to the PLC.
The init.c file has commands to initialize the motors and set the initial parameters such as velocity and acceleration. The cyclic.c file has a state machine which the robot will follow. The state machine following only a few simple states. Once the motors and powered and ready, they are switched to home position. Then once they are homed, the velocity of motors is set to a '1' and using a counter and a clock we are able to make the motors more for the time specified (move downwards). Once they had moved for a specified time, they will go into the idle state where there is another counter which helps to control the amount of time motors will rest. Once they rested for some time, they will move on to the last state of motion, which most likely has the directions of motors inverted to reverse the direction of the robotic arm (make it move upwards). After this state it will go back to its home state, and repeat this cycle. You can see a flowchart of the state machine in Figure 34 below.
We have tested this program and it was successful in performing the required motions. As you could see, so far we have used time as our variable for controlling motion, but in the upcoming semester we will start using motors' positions as well.

D. Appendix Mechanical Drawings and Support Documentation

The following section has the mechanical drawings, of the components we planned on using in the arm structure of the robotic arm. We are missing drawings for the base due to how fast that had to be assembled, but it served as a way to prototype a base design which helped gives us some insight into how to advise our sponsor in building a metal base.

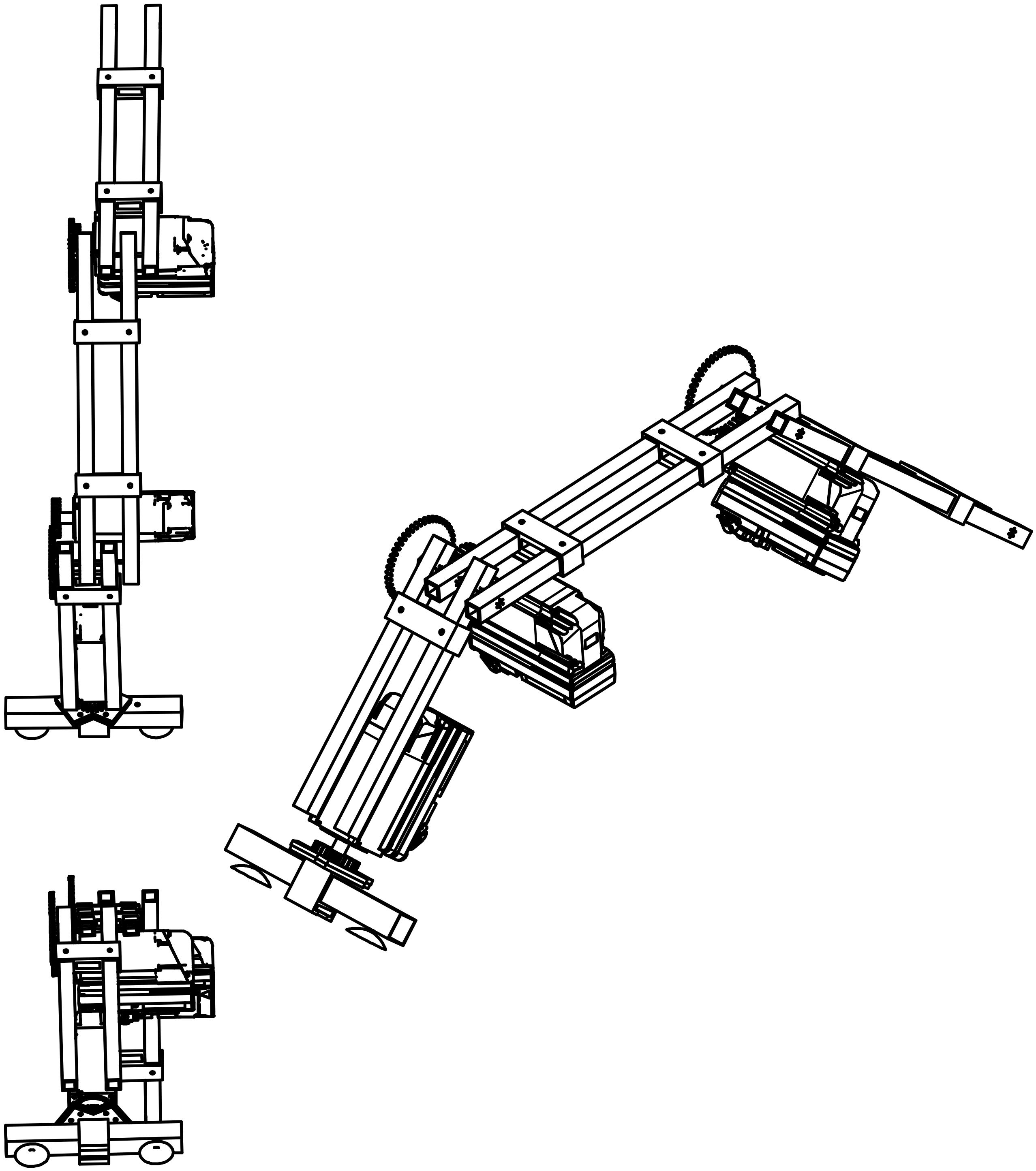
1) The first two drawings are of the whole arm put together showing how it might have looked like.
2) The third drawing shows the camera suction bracket that will be attached to the end of the arm.
3) The following sets of drawings are of the struts of aluminum that actually make up the arm and joints.





DRAWN Aaron	9/21/2015	
CHECKED		TITLE
QA		
MFG		
APPROVED		

SIZE A4		DWG NO Arm assembly1	REV
SCALE 0.13 : 1		SHEET 1 OF 1	



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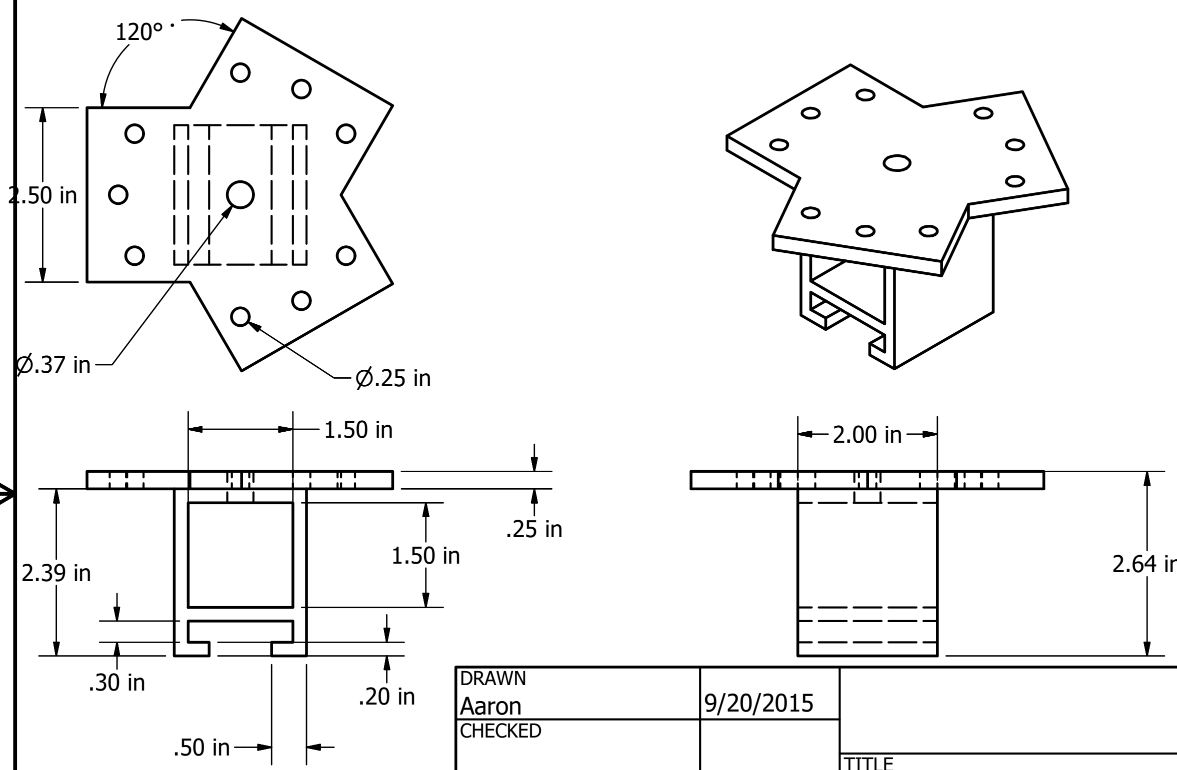
		SCALE 0.1: 1		SHEET 1 OF 1	



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MFG		
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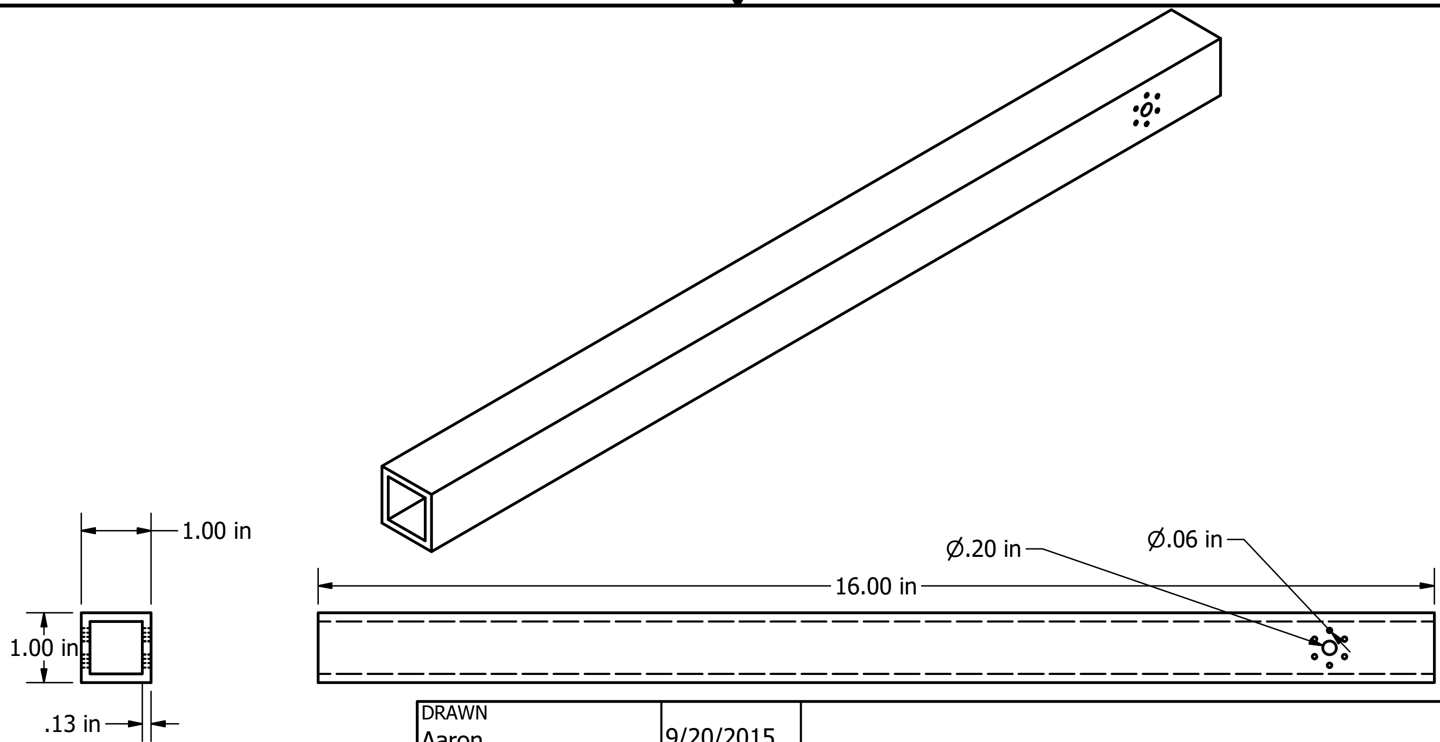
		SCALE 1 / 2 — SHEET 1 OF 1



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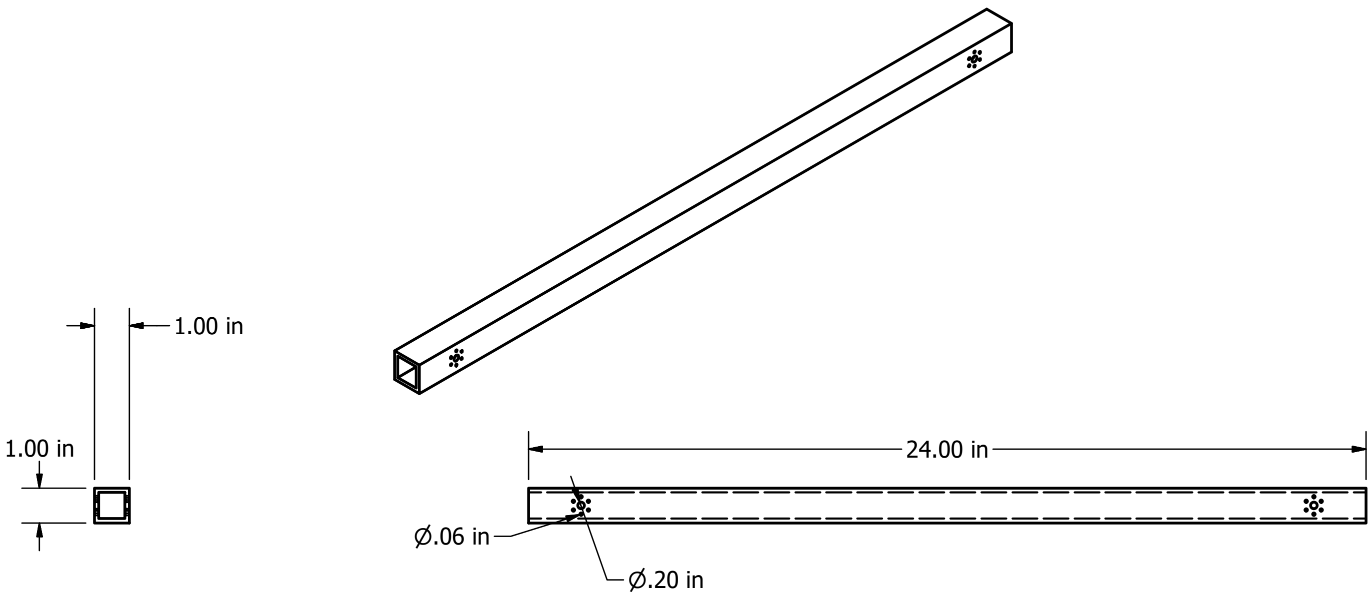
APPROVED		

SIZE A4 | DWG NO hand | REV

SCALE 1 / 2 | SHEET 1 OF 1



DRAWN Aaron	9/20/2015				
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MFG					
APPROVED					
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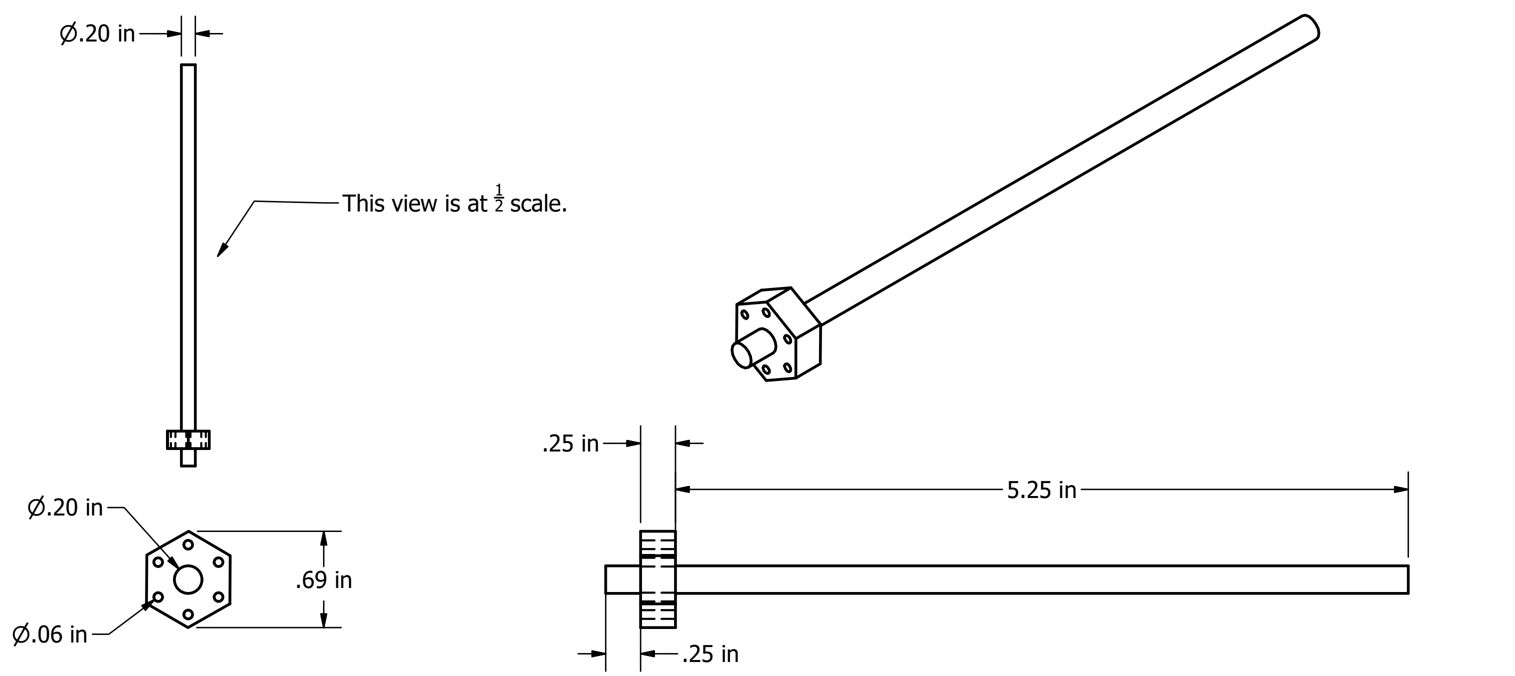
		SCALE 1 / 4		SHEET 1 OF 1	



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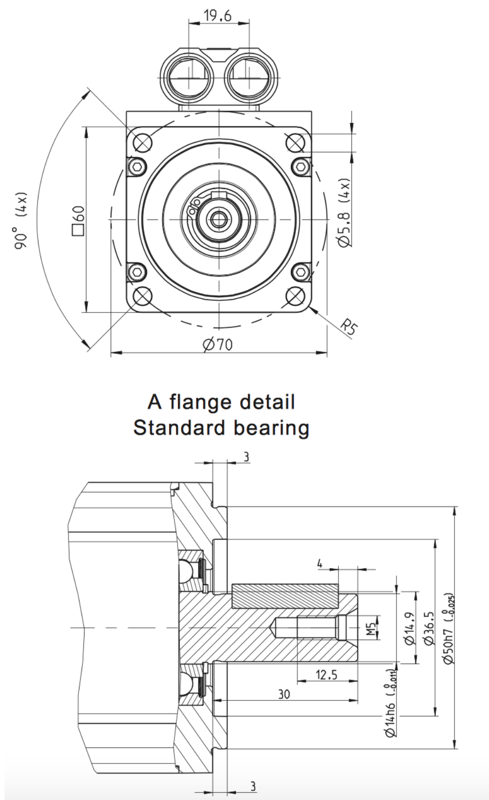

Fig. 30: 8LVA23 Motor Overview [27].

These drawings were all our original plan, and we have strayed from the plans. We have learned a lot about how mechanical engineering could work through an iterative process, which is not the way that professional mechanical engineers would approach the design. But it has proved to be a great learning experience none the less.

E. Appendix Vendor Contacts

From the very beginning, our Vendors we contacted were DST Output, our current sponsor for this project, B&R Automation, and VacMotion. The primary reason for contacting VacMotion was to inquire about the Vacuum System components and their advice. We were able to receive advise on the amount of suction cups we should use and what are the effects of having many suction cups. After their advice and some research, we were able to purchase the Vacuum System components and received positive results.

We have reached out to our sponsor DST Output many times who provided us with any extra hardware needed as well as technical support. We worked with their firmware and electrical engineers who have helped us to set up the equipment they provided and start programming it. To increase our efficiency we also have set up communication links with the vendor of our motion control equipment, B&R, for technical support as well.

Another resource we have used is the Physics tutoring center on Sacramento State campus. We have worked with tutors to get help with physics calculations in order to figure out the gear ratios needed for our gear system. They were very helpful to us.

F. Appendix Resumes

Igor Pishtoy

OBJECTIVE: Seeking an engineering position in the Computer Engineering field.

EDUCATION:

In progress: **BS, Computer Engineering** ▪ CSU Sacramento ▪ Spring 2016

Courses:

Computer Hardware System Design*	Advanced Computer Organization	Computer Networks & Internets
Operating System Principles*	Advanced Logic Design	Signals & Systems
Data Structures & Algorithm Analysis	Computer Interfacing	Network Analysis

*Spring 2015

PROJECT EXPERIENCE:

16-bit MIPS CPU:

Led a two-person team through the design, development and simulation of a 16-bit datapath and control unit for a 5-stage pipelined system. After designing the datapath and control unit, we modeled and simulated each component of the system in Verilog. Branch prediction, forwarding unit, hazard detection unit, load/store word, ALU, register file, and pipeline buffers were also implemented.

Remote Controlled Surveillance Vehicle:

Led a four-person team through the design, development and implementation of a remote-controlled robot using a Propeller microcontroller and an RPi. The robot was controlled via Wi-Fi with live-stream video and Secure Shell prompt to move the robot via a laptop's keyboard as input.

Church Website: **http://iucecb.azurewebsites.net/**

Member of a four-person team, designing and implementing a Church website for the International Union of Churches of Evangelical Christian Baptists. The design is strictly following the SDLC Waterfall model, using Visual Studio 2013, with an ASP.NET MVC Framework. A SQL database in MS Azure is used to store user and backend driven information.

Offensive Security:

Operated a local Offensive Security lab via Kali Linux's Penetration Testing tools. This includes: DNS and Mac Spoofing, Nmap, NetCat, Wireshark, and UDP port scanners. Attacks such as: DDOS, MITM, Metasploit, Windows Reverse TCP, WPS, bruteforce, dictionary, and other social engineering tools.

COMPUTER SKILLS:

<u>Programming:</u>

C ▪ C# ▪ Java ▪ Visual Basic ▪ x86 Assembly ▪ Verilog ▪ VHDL ▪ Bash scripting ▪ Python ▪ HTML MS SQL Server ▪ CSS ▪ JavaScript ▪ ASP.NET MVC

<u>Hardware Testing Devices:</u>

Function Generator ▪ Digital/Analog Multimeter ▪ Oscilloscope ▪ DC/AC Power Supplies ▪ Logic Analyzers ▪ Arduino ▪ RPi ▪ Parallax Propeller ▪ Amani ▪ Pickit 3

<u>Software:</u>

Visio 2013 ▪ MS Office ▪ Visual Studio 2013 ▪ iWork ▪ VM's ▪ MultiSim ▪ PSpice ▪ Xilinx ISE ▪ MatLab

<u>OS Platforms</u>: Windows ▪ Linux ▪ MS-DOS ▪ Mac OS X ▪ iOS

WORK EXPERIENCE:

Hewlett Packard – Storage Engineering Intern **06/15/-Present**

Medisys Consulting, Inc. – Junior Consultant/Developer **03/15-06/15**

Apple Inc. – Apple Tech Support (iOS/OS X) **05/13-09/14**

ACTIVITIES AND ACCOMPLISHMENTS:

▪ Dean's Honor Roll List ▪ MESA Engineering Program (MEP) ▪ Society of Hispanic Engineers (SHPE)

▪ Sacramento CAL-SOAP Scholarship ▪ Athlete of the Year Award Scholarship

Aaron Sotelo Sahagun

OBJECTIVE: An internship position in the Computer Engineering Field.

EDUCATION: **BS, Computer Engineering** • CSU Sacramento • 3.003 GPA • **May 2016**

***RELATED COURSES*:**

Intro to Computer Architecture	Intro To Logic design	Computer Hardware Design
Programming Concepts+ Method 1 & 2	Electronics	Computer Interfacing
Intro to System Program Unix	Signals and Systems	Operating System Pragmatics *
Intro to Circuit Analysis	Operating System Principles	CMOS and VLSI *
Engineering Graphics+ CADD	Advanced Logic Design	

** In progress as of Spring 2015*

SKILLS:

Computer Languages:
Java, C, Verilog, VHDL

Software Applications:
Autodesk Inventor, Microsoft Office, Xilinx ISE, Multisim, PSPICE, Cadence Virtuoso

Languages:
English, Spanish

Hardware:
Soldering, Arduino Platform, Raspberry Pi Platform, Amani GTX PLD, Spartan-3e FPGA

PROJECT EXPERIENCE:

Raspberry Pi, Face Tracking Nerf Turret

Used a Raspberry Pi to implement Face tracking software. Modified face tracking software to control a shooting sequence that fired a Nerf toy at centered target's face. Firing mechanism was created with a pair of Arduino controlled relays.

4x4x4 Led Cube

A matrix of LEDs soldered in a cube form and wired to be controlled by a single Arduino micro controller. Wrote code that cycles through all LEDs one by one, and in multiple patterns.

Electrocardiogram

Worked in group to build an ECG using only Op Amps by using the theoretical concepts of operational amplifiers (op-amps), instrumental amplifier, active low pass filter, passive high pass filter, and common mode rejection the ECG circuit was built.

RELATED EXPERIENCE:

Intern — ***Intel Ultimate Engineering Experience*** — *06/2013-08/2013*

- Participated in a 6-week engineering program designed to provide hands-on technical engineering experience through a variety of technical skill development activities, team-based project work, competitions, professional skill development, networking, and social activities. Highlights of the program included:
- Building a quadcopter and programming its sensors and motion to achieve stable flight.
- Designing and programming a computer game using JavaScript.
- Working in teams, building problem-solving skills, and using critical thinking to create technology-related solutions for local community issues (ideation)

WORK EXPERIENCE:

Sales Associate — **The Home Depot** — 5/2012 to present

- Provide fast, friendly service by actively seeking out customers to assess their needs and provide assistance.
- Work in cooperation with Department Supervisor and other associates in their department as well as other sales departments to provide a good customer experience.
- Provide customers with product knowledge, providing information on product features, and knowing related items to sell an entire project.

VOLUNTEER WORK:

MEP Mentor Program, Academic Mentor — **CSU Sacramento, MEP** — 01/2013 to present

- Schedule weekly meetings with freshman mentee and provide guidance for first two semesters for the freshman mentee.
- Schedule monthly meetings with freshman mentee and professional mentor for professional development.
- Help freshman mentee succeed academically, by providing a support system and encouraging time management.

PROFESSIONAL ACTIVITIES/ACCOMPLISHMENTS:

- SHPE Member
- IEEE Member
- Dean's Honor List
- MEP Member

Working 24 hours per week, while carrying 16 units per semester and maintaining a 3.00 GPA

Sergey Selyuzhitskiy

OBJECTIVE

Obtain a career in the field of Computer Engineering.

EDUCATION

In Progress: **Bachelors of Science, Computer Engineering** - CSU, Sacramento – Spring 2016

KNOWLEDGE & SKILLS

Communication:

Effective in face-to-face communication as well as public speaking. Easy to talk to, have a sense of humor, can work extremely well in a team-oriented environment. Team player, have much of leadership experience.

Problem Solving:

Strong analytical and problem-solving skills. Ability to analyze given data and troubleshoot effectively, as well as finding the simplest solutions.

Bilingual:

Fluent in English & Russian languages.

Program languages*:* C, Java, Python, Verilog, VHDL, x86 Assembly

Operating Systems*:* Windows, Macintosh OS, Linux

Hardware: Raspberry Pi, Diligent Analog Discovery, Arduino Propeller, Amani FGA, Spartan 3E FPGA, Microchip PICkit3; Agilent Oscilloscope, Circuit construction; B&R PowerPanel 420 embedded with B&R ACOPOSMicro system.

Software: Xilinx, MultiSim, PSpice, Microsoft Office, B&R Automation Studio 4.2

EXPERIENCE

AppleCare Technical Advisor **Apple Inc.** **06/01/2011 – 06/01/2012**

Guided customers over the phone to identify any issues with their Apple computers and helped to have the issues resolved. Maintained control of the calls with a wide range of customer of different age, gender, ethnicity, ensuring to leave them satisfied with Apple's technical support even if they have had any frustrating experiences with Apple's products.

Manager / Dispatcher **OK Transport LLC** **04/01/2015 – Present**

Found and scheduled loads for transportation. Scheduled pick up / drop off times with customers. Managed finances and kept financial records. Assisted driver with transportation of loads.

PROJECTS & ACCOMPLISHMENTS

Robotic Arm:

In a team of four, successfully built a working prototype of a robotic arm. Sponsored by DST Output, our team has put together systems for Robotic arm with the function of sorting cardboard sleeves: analyzing the sleeves with machine vision and using the robotic arm to relocate them. Responsibilities included seeking and obtaining support for our systems from our sponsor and vendors of our equipment; verifying the motors provided by our sponsor fit our needs; and programming our system (consisting of a PLC, 3 drivers, and 4 motors by B&R) with automation software in order to fit our needs. Project still in progress and will be worked on and improved during the next Spring '16 semester to satisfy our Senior Design course requirement.

BrainWave Controlled Remote Car:

In a team of four, successfully built a wireless remote car, which was controlled through a BrainWave Reader. Were successful in controlling the remote car to drive forwards or backwards depending on the attention level of the person wearing the BrainWave Reading headset. Used the Arduino board and Bluetooth for communication and control, and used Raspberry Pi to transmit a live stream video from the Remote Car to a local network.

Joseph Gonzalez

J.Gonzalez.E@ieee.org
www.jgonzalezcpe.com

EDUCATION:

In progress : Bachelor of Science, Computer Engineering, CSU Sacramento

Courses:

Intel x86 Computer Architecture	Signals and Systems	Electronics Analysis
Data structures and Algorithms	Operating System Principles	Programming Concepts and Methodology
Network Analysis	Computer Networking and Internet*	System Programming in Unix
Computer Interfacing	Advanced Logic Design	
Computer hardware system design	Intro Elect Circuits/Devices Analysis	

** In progress as of Fall 2015*

PROJECT EXPERIENCE:

Impact Belt

- Game published on Google Play Playstore
- Utilizes Google Services APIs
- Built in Eclipse IDE (Java)
- Andengine Game Engine
- Box2d Physics Engine
- MySQL Database Management System

https://play.google.com/store/apps/details?id=com.quantumQship

Safety Sam (Child traffic controller)

- Smart mobile traffic controller
- Designed as a finite state machine
- Created to keep children safe when playing near traffic
- Fully autonomous robot • Hardware:
  - Arduino Uno
  - Raspberry Pi
  - sonic sensors, LEDs, buzzers, servos, camera

Arcade System

- Classic table-top arcade emulation system
- Fully fabricated and designed by hand
- Sand-boxed experience for the end user
- Built using Intel based computer
- Scripts to ensure multiple sequential program cooperation
- Hardware and software interact seamlessly
- Analog to digital devices interfacing

Intel Ultimate Engineering Experience Quad-copter/Game

- 6 week program emphasized group skill development
- Built a quad-copter powered by the Arduino Uno
- Connected to Bluetooth and WIFI peripherals
- Using Microsoft XNA tools created a 2d shooter style game
- Both projects were constructed using the professional method of engineering life cycle

KNOWLEDGE AND SKILLS:

Programming: Java, Andengine (Android Game Engine), Box2d Physics Engine, C, C#, Verilog, VHDL, Intel Assembly, UML, XML

Software: Eclipse, Google Services APIs, IntelliJ IDEA, Microsoft office Suite, VMWare, Cadence Suite, Xilinx ISE, Altera Quartus II, National Instruments Multisim, Putty, Cadence Pspice

Systems: Windows, Linux, Unix, OS X

Hardware: Raspberry Pi, Digilent Analog Discovery, MicroChip PICkit3, Parallax Propeller, Arduino Platform, Spartan 3E FPGA, Amani FPGA, Tektronix DPO Oscilloscope, HP 33120A Multimeter

WORK EXPERIENCE:

Studio Operator: Independently operated a video/audio recording studio for on-line class streaming and live cable TV broadcast. *CSU Sacramento* 8/12- 1/14

Apple Care Advisor: Assisted customers with precise problem solving solutions to a wide array of issues. *Apple Inc.* 5/11- 10/11

Performance Engr. Intern: Created tools to aid in automation of data processing. Hewlett Packard Enterprise 5/15- Present

ACTIVITIES AND ACCOMPLISHMENTS:

-Four time Dean's Honor List recipient
- Society for Hispanic Professional Engineers
- Intel Ultimate Engineering Experience
- IEEE Association
- Tau Beta Pi Engineering Honors Society

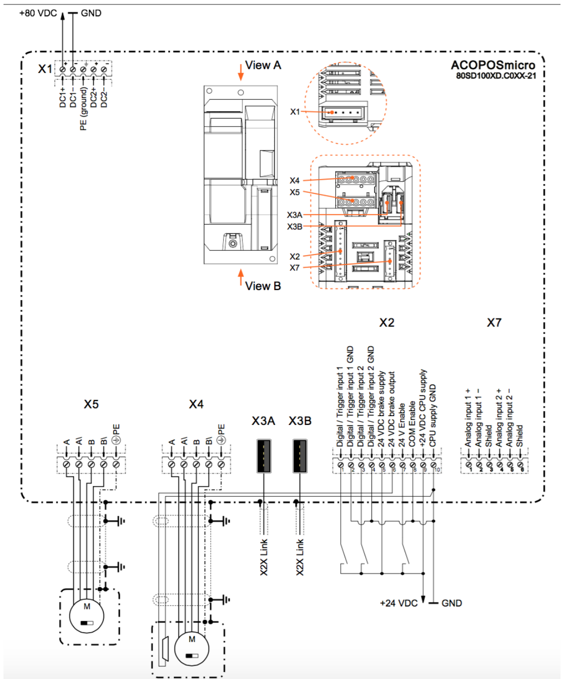

Fig. 31: D100 Driver Schematic [28].

Fig. 32: Sample from library [29].

Fig. 33: Sample from library [30].

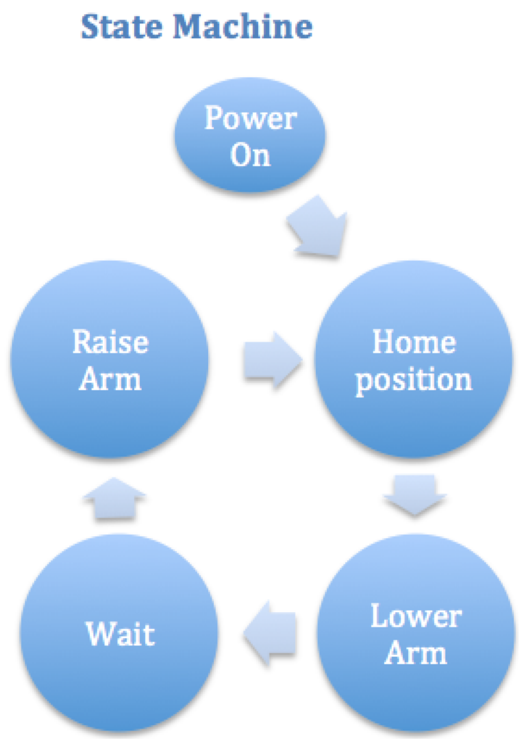

Fig. 34: Overview of the State Machine [31].