Multi-Purpose Automated Robotic Arm

DESIGN DOCUMENT

Team: SDMAY19-31
Client: Alexander Stoytchev
Advisor: Alexander Stoytchev

Brett Altena – Team Leader, Computer Vision Developer
Amos Hunter – Meeting Scribe, Electromechanical Specialist
Drew Caneff – Electromechanical Engineer, Accountant
Jase Grant – Assignment Manager, Embedded Systems Engineer
Kristian Wadalowski – Report Manager, Front End Developer

Team Email: sdmay19-31@iastate.edu
http://sdmay19-31.sd.ece.iastate.edu/

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● mpARM: multi-purpose Automated Robotic arM

● ISU: An acronym for Iowa State University

● Computer Vision: A technology which allows a computer to receive information from a camera or similar device and process that information in such a way as to interpret it and produce a response accordingly

● Iowa State: An abbreviation for Iowa State University

● mpARM : Multi-Purpose Automated Robotic Arm

● LED: Acronym for light-emitting diode

● FPGA: Field Programmable Gate Array, a kind of programmable microchip

● IDE: Integrated Development Environment, a software platform for writing code

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1. Introduction

1.1 Acknowledgement

The Multi-Purpose Automated Robot Arm team would like to kindly thank Professor Alexander Stoytchev for allowing members of our undergraduate team to participate in his graduate level course on computer vision which provided our team the ability to develop our vision into a reality. Additionally, we would like to thank Iowa State University for providing the necessary funding for our team and allowing us to utilize a wide range of campus resources over the course of the project's development phase. We would also like the time to thank the designer of the THOR arm AngelLM and the rest of Team 3 of the Hackaday organization who made their robotic arm plans available online. The designs they provided drastically decreased the amount of time and money needed to produce a robotic arm.

1.2 Problem and Project Statement

As a result of increasing production costs for food related products in the restaurant industry, coupled with work related injuries in kitchens and a lack of product consistency, both the producer and consumer are negatively affected. Food producers are forced to increase costs to deal with ever-increasing wages as well as cover medical expenses for injuries sustained in the workplace. As costs increase so does the price of the goods a consumer purchases. Consumers must also accept that at times, as a result of human error, the food they get might be inconsistent with the previous experiences they've had at the same establishment.

To combat this issue, automation in the form of a robotic chef will be implemented in the workspace. This solution aims to revolutionize the restaurant workforce with not just better service, but with a better product as well. While the end goal is to produce an automated system which could produce a variety of different food options, our team will be solely focusing on the production of pancakes as a proof of this concept. Equipped with multiple arm utensils coupled with computer vision, this system will be able to perform the same tasks as a human cook and more. An automated cook will work highly efficiently and would require no breaks, not suffer from fatigue, and create a consistent product every time. With the implementation of an automated chef arm the cost of labor included in preparing the food could be greatly reduced.

1.3 Operational Environment

The intended operating environment for this product is commercial and home kitchens. This product needs to be able to withstand intense heat produced from the oven, grill, or fryer, as the product will be in close proximity to these on a regular basis. Additionally, some components directly interact with these hot surfaces, and thus must be heat resistant to match. High humidity, is also an expected environmental hazard. This could lead to condensation on the product, and thus requires a degree of waterproofing to prevent the product's electrical components from shorting out. The product is likely to be used in a kitchen near humans, and as such we must ensure proper safety features are incorporated to accommodate this. Finally, our product will be handling food intended for public consumption. This requires that our product meet strict standard for sanitation, as failure to do so could lead to health concerns for the consumer, and possibly litigation.

1.4 Intended Users and Uses

Project mpARM aims to modernize the cooking experience in both professional and home kitchens. As a result of having two possible environments, mpARM will have two primary users, the first being restaurant employees who regularly interact with the product in the workplace. The second user base will be ordinary people looking for assistance in preparing meals in their own home. While the primary objective of both users is similar in that they both require help in food preparation, the two groups will expect different end results as their needs are slightly different from each other.

On a commercial scale, restaurant employees will require the ability to produce a handful of carefully crafted recipes quickly and efficiently. Having the ability to perform a lot of tasks is important. However, it is just as important to deliver a product that is consistently good as well as quickly produced. In commercial kitchens it is unlikely to find a single employee performing all the tasks as it would result in a bottlenecking of the workflow. It is much more commonplace to see a variety of workers focusing on a limited amount of tasks at predetermined stations. By working in unison, a group of cooks are able to produce a variety of dishes quickly. It is necessary that individuals working in a commercial kitchen keep in sync with one another so as to not disrupt the flow of food leaving the kitchen. These employees (and effectively our users) will expect that whatever product is provided to them does not hinder the system they have already established, but instead enhances it.

Everyday people preparing food for themselves operate on a different system. These individuals likely require a variety of different food options compared to restaurants. These users desire a device to do all their cooking for them rather than simply help. Speed is just as important for the individual at home as it is for the team working in an industrial kitchen. These users require a system that can make excellent food with little assistance on the users' behalf.

1.5 Assumptions and Limitations

Assumptions:

- The input product such as batter will be similar in size, shape, and location relative to station is consistent.
- Once the system is programmed to work in certain conditions those conditions remain the same. An example would be that once the robot gets used to the height of a stovetop the user doesn't change that height.
- The location of the pancake once the batter has been poured remains the same.
- If any additional tools are required to prepare the dish, those tools remain in designated locations.
- The locations where the dish is being outputted remains the same.
- Robot will be fed required inputs such as batter and will not be required to prepare its own.

- Pancake batter will be consistently made every time utilizing the same recipe so as to provide a consistent input.

Limitations:

- The system will require users to provide required materials such as pancake batter.
- The cost of the unit has to remain under $1500.00US.
- Required space must allow for a robotic arm to fully maneuver.
- System will assume that it will be provided with the required materials. For example, if the user placed materials for making burgers, but selected the pancake setting the robot would assume that the materials placed in zones corresponds to making pancakes not burgers.
- System will assume objects such as the stove top are properly prepared and ready to perform desired tasks.

1.6 Expected End Product and Deliverables

The final product will be split into two parts. The first step is to produce a mechanical system that can reliably and accurately produce pancakes. The second part is comprised of a computer learning system which can determine the status of the dish. When in unison, the system will be able to determine the status of the dish and act accordingly so as to provide the perfect product on a consistent basis. The final product should specialize in the industrial environment, but should be applicable in a household system. Consideration should be taken in regards to the power as a standard 120 volt AC power supply should be applicable to all models. The automatic pancake making system will be user friendly, being easy to operate and maintain. The dates and corresponding deliverables leading up to the final product are given below.

Prototype - December 6th, 2019

- The prototype will be a proof of concept and will consist of a rough design 3D printed robotic arm with basic motion abilities. At this point the computer vision is unlikely to be completed, but the physical design should be well on the way.

April 27, 2019

- The system should be able to fully function on both a physical and software level.
- Project Proposal Accepted
  - Expected Delivery Date: 1 Month
  - Description: The proposal is accepted, and the project can continue.
- Demonstrate a responsive user interface
  - Expected Delivery Date: 6 Months
  - Description: The chassis will be assembled and the beginning of the software program will be tested.
- The mixture is poured properly onto the flattop.
  - Expected Delivery Date: 7 Months
  - Description: The robotic arm will be assembled with working stepper motors and encoders, demonstrating controlled pre-planned movement from one position to another.
- Computer vision system detects when a pancake is ready
  - Expected Delivery Date: 8 Months

    - Description: The computer will be connected to the camera and be able to tell when the pancake is ready to flip via analyzing the surface bubbles on top of the cooking pancake.
- The robotic arm can move on demand and flip a pancake
    - Expected Delivery Date: 9 Months
    - Description: The robot arm can move quickly enough to flip a pancake in the same place with demonstrated efficiency.
- Pancakes are made
    - Expected Delivery Date: 10 Months
    - Description: The entire system is working properly together, where users are able to submit their request, and have it served to them a set amount of time later.

2. Specifications and Analysis

2.1 Proposed Design

Robotic Arm:
The prototype currently has several drafts which are theoretically capable of cooking of pancakes in the absence of a human chef. Although all of these prototypes are based off of the THOR robotic arm designs, they differ in many ways including the arm attachments being used to interact with the pancakes and corresponding ingredients and the question of whether the robot should be installed on a countertop or be mounted above the work surface. Currently, none of these prototypes have been constructed and only exist as ideas and sketches, however, plans to create the THOR arm are commencing. Since the THOR arm design is an overlapping element between all arm-based prototypes it will be relatively easy to modify the THOR arm base so as to test the variety of ideas the team has in mind.

Other elements all conceived prototypes have in common correlate to the functional and non-functional requirements as dictated by the task the robotic arm is expected to perform and environment in which the device is meant to function in. The robotic arm must first and foremost be able to perform the task of making a pancake from batter to serving the dish on a plate for human consumption. The robot will have to maneuver in small environments where hazards such as sharp objects and open flames are present without harming nearby humans who share the same space. Additionally, the robot will have to adhere to proper sanitary regulations present in commercial restaurants. Lastly, the robotic arm will aesthetically be comparable to that of a kitchen appliance. This product won’t look jarring in the kitchen landscape and must instead blend in like other autonomous machines which help in day to day kitchen activities. When testing our various prototypes, these requirements will be met in order to satisfy the customer which is why the final solution will have to encapsulate all of them.

The design of the THOR robot arm is ideal for this task as the arm has been crafted in such a way so as to maximize the balancing of the included features. Any add-ons created or any payload attached to the end of the arm would need to exceed 750 grams before counterweights would need to be attached to the robot for the servo motors to properly maneuver the device. The design of this arm is also ideal for this project, because a power distribution board is included in the materials. This allows for signals controlled by a microcontroller (Arduino Mega) written in a C based language to drive the servos using motor controllers attached to the power distribution PCB. This simple line of communication between the program and the physical components allows this robotic arm to be easily incorporated into a wide array of projects and perform a multitude of tasks which is ideal for our team.

Presently, our design places the robotic arm mounted with its base upward. It will be bolted into position on a metal frame, so balancing the robot is not an issue. It therefore does not need special equations or algorithms to remain in place. However, care is taken within coding that the arm remain within the frame enclosure. In essence, the robot is hard-coded to not utilize its full range of motion and instead remain within fixed degrees of freedom to perform its task.

Computer Vision:

The computer vision system is composed of an overhead camera connected to the FPGA in the embedded system. The camera will be held by a tripod so that its field of vision will contain the entirety of the griddle. There are multiple methods on how to implement the software that will determine when the pancake should be flipped and served. The first method is detecting the amount of bubbles that rise onto the surface of the pancake and determining if it passes a set bubbles to pancake surface area ratio. The third method is not implementing any smart image processing algorithm and setting a timer for each pancake in sight for both sides of the pancake. Right now, the planned approach is detecting the amount of bubbles that appear on the surface because buying a camera that reads internal temperature is too expensive and the third method is being implemented after the pancake is flipped. Each method has been researched with a variety of potential products that can be used to accomplish each method.

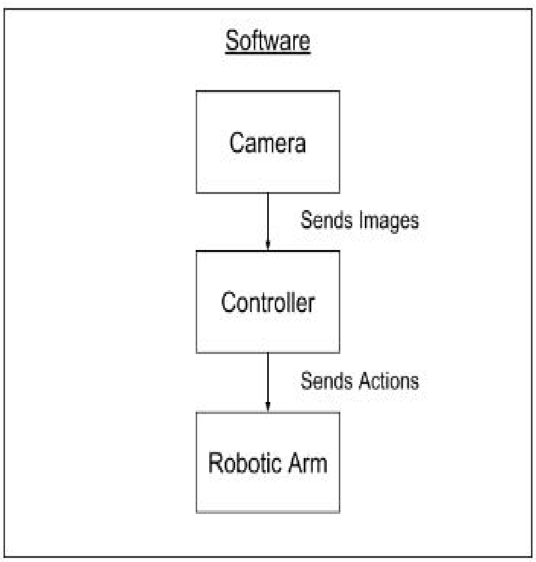

Fig. 1: Robotic arm hardware and software flowcharts

Functional Requirements

- The camera has a frame rate of 60 FPS
- The camera can see each pancake within its field of vision

Non-Functional Requirements

- The connection is reliable between the camera and the embedded system
- The image processing is scalable for increasing amount of pancakes
- Computer vision system requires little maintenance

Electrical and Mechanical Systems:

A number of possible design concepts have been considered by our team for this project. An initial consideration we addressed was whether or not a robotic arm would be an ideal solution for our requirements. A few alternatives were considered. One option was a conveyor belt system similar to what is used in factories which produce frozen pancakes. Another option was an appliance type machine which could be a modular device similar to what is currently used in homes and the hospitality industry. It was even considered that we use 3D printed food technology. Ultimately, it was decided that the robotic arm morphology satisfied the needs and desires of our client the best.

Once it was determined to continue with the robotic arm direction, new choices presented themselves. At one point it was intended that the pancake batter would be stored in a tank and then a small pump would pump it through a tube and then out a nozzle onto the griddle. Later, after some consultation with our advisor, it was determined to place the batter in a tank above the griddle, allowing gravity to feed the batter through a valve and thus eliminating the need for a pump. Another similar design choice was the style of griddle. A circular griddle which would spin was evaluated, as well as a shaped griddle with concave indentations to hold pancakes as they cooked, but finally it was resolved that a flat rectangular griddle would be used. Another key decision was the location to mount the camera for the computer vision. One idea was to mount the camera on the robotic arm itself, but it was found that this would be very problematic for the software implementation. It was found to be more reasonable to mount the camera on a stationary structure such as a tripod or gantry.

Furthermore, deliberation was given to non-functional aspects of this design as well. Aesthetics have been taken into account, particularly since a major appeal of the device will be its appeal to consumers and patrons. Therefore, a sleek, modern appearance is preferred, and the electrical and mechanical components conform to those ends. This design choice also makes the device easier to clean. Aside from the improved appearance and cleanliness, such a form factor improves food safety, another important consideration. It is of equal concern that this device is not a fire or electrical hazard. To these ends, wires, cables, connectors, and similar components will be kept in appropriate housings and harnessed adequately. The griddle, power supply, and other such elements have heat management accounted for in the form of heat sinks, proper venting, and heat resistant materials around them. Electrical safety has been achieved by properly grounding and insulating all of the electrical components. In addition, there are precautions taken for the effects of electromagnetic interference. Proper shielding of electronics (especially the microcontroller and other controls) ensures that electromagnetic noise and crosstalk do not cause problems.

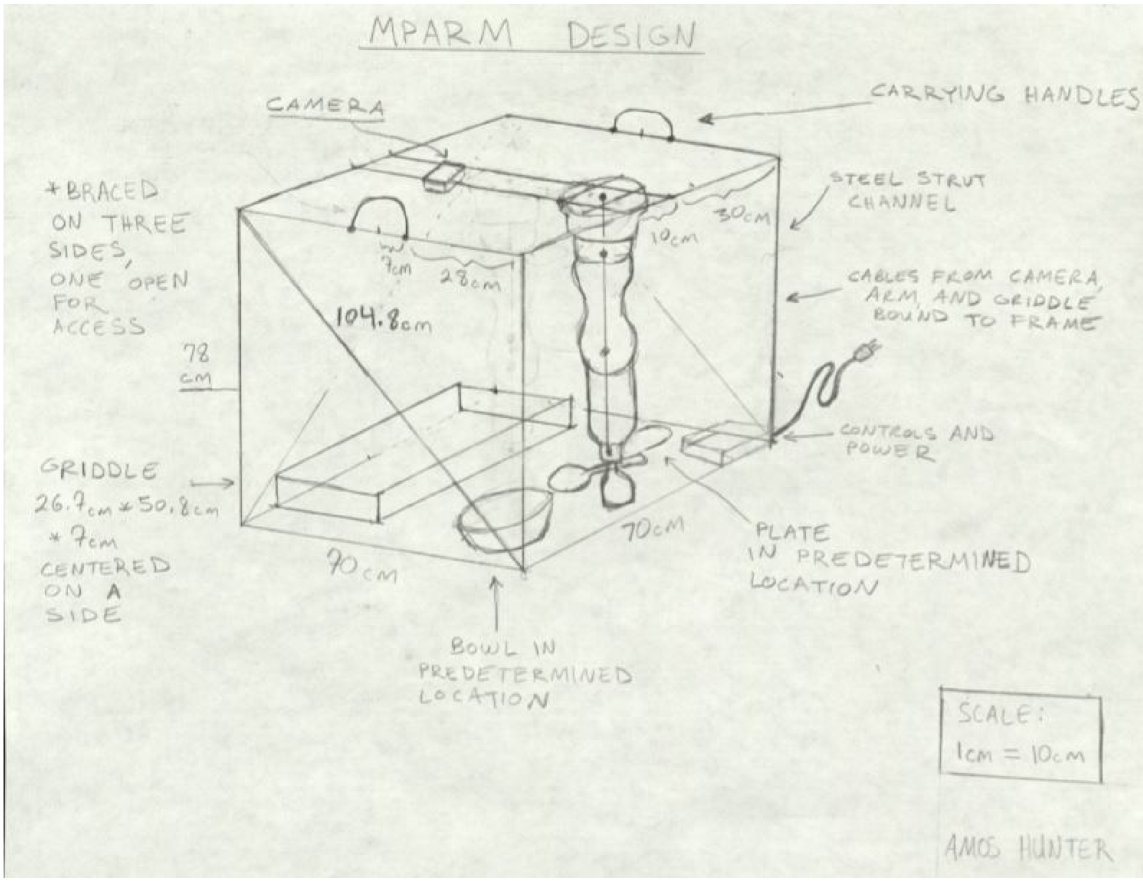

Fig. 2 Electro-mechanical overview

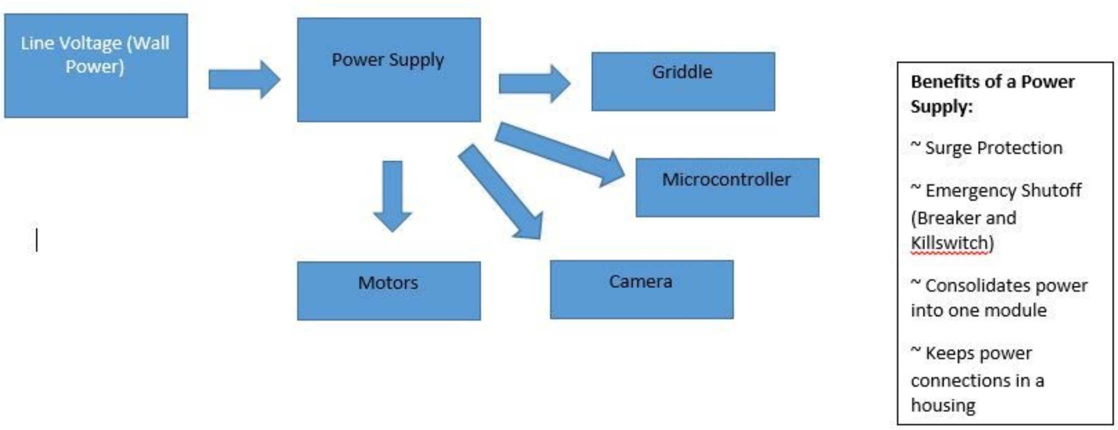

Fig. 3 Electrical system overview

Embedded Systems:

Multiple designs and a lot of research on a FPGA that could handle all the inputs and outputs that will be needed in a timely manner have been done. At this point in the project they have not been tested yet, but will be soon.

This project's functional requirements are that the inputs are dealt with correctly and outputted correctly and that there is enough input ports for all the components that need to be interfaced with the FPGA. That is the same with the output ports. There needs to be enough so that the components that need information sent to them will have information sent to them. The non-functional requirements would be speed, because if it is to slow it the pancakes will burn. Also receiving all the inputs correctly will be a requirement (which will make it run slower), because it there is sixty frames per second.

The controller sends motor control signals to the robotic THOR arm. These signals regulate the power of the motors to position each joint at the proper angle. The speed and torque of each motor is adjusted correspondingly according to the physical and software constraints.

In a higher level view, the controller determines these signals based on the information it receives from the computer vision module. When the computer vision software determines that adequate bubbles have formed on a pancake, it will send a signal to the FPGA which will cause a sequence of motor commands to be sent. These commands will cause the arm to flip the pancake. The software then allows a brief timer to count down from a pre-chosen value (found from calibration of a pancake recipe). Once the time is up, a similar motor control signal process is issued from the FPGA which will cause the robot to place the pancake off of the griddle and on to a plate. New batter is added by the user as needed.

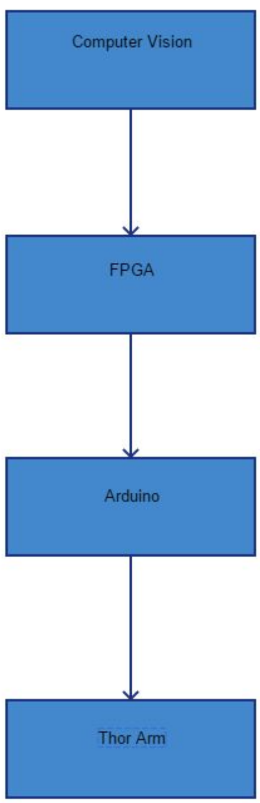

Fig.4 Inputs and Outputs of FPGA

2.2 Design Analysis

Robotic Arm:

One of the most noteworthy design decisions is the decision of using a robotic arm for this task. Initially, many ideas surrounding how the pancakes would be produced were suggested. Everything from conveyor belts to pre-packaged goods were suggested, but a robotic chef was the chosen method. Sketches and models have been constructed. Our team will construct a basic robotic arm in which the various designs may be implemented and later tested. There are a variety of pros and cons this team was able to identify about this system when determining our method of pancake production. Some of the pros include having the ability to make a variety of different dishes, being able to be implemented in a diversity of kitchen environments, having the ability to work with tools initially designed for human use, ease of operation, and ease of cleaning. Some of the cons the group determined were it cannot make food as fast or as efficiently as other food production methods, the device is complex and could be prone to breaking, and it will require a fair amount of installation when being incorporated into an existing space. Despite this system having flaws, the pros outway the cons when considering what our group hopes to accomplish with this project.

The First Prototype: FlipJack

The FlipJack automatically pours pancake batter, cooks pancakes, flips them, and then serves these pancakes. The entire process is automated by an Arduino Uno keeping time and controlling servo motors. The pancake making process can be done in three stages: dispersal, the first side, and the second side. The dispersal stage consists of sliding a 3D printed gate to a set location to allow the flow of pancake batter from the batter containers onto a metal sheet. The first side stage consists of cooking the first side of the pancake for ten minutes to allow the side to brown thoroughly without burning the pancake. The transition to the next stage happens by a servo flipping the piece of sheet metal 180 degrees so that any pancake being cooked is moved onto the next piece of sheet metal. After this transition is complete, the dispersal stage is repeated so that the next set of pancakes starts to cook. The second stage consists of cooking the opposite side of the pancake for ten minutes. After the completion of this stage, the second piece of sheet metal is flipped 180 degrees and the fully cooked pancakes are dropped onto a serving platter.

Fig. 5 Flipjack Prototype and creator Brett Altena

How we built it

The pancakes are cooked by a simple, off the shelf griddle. Our design builds off of this basic product to add automated features. To pour the pancake batter we suspend containers of batter over the griddle with a wooden construction and custom designed 3D printed valve parts. Rather than attempting to insert a spatula under a cooked pancake, we simply cook on pieces of sheet metal attached to a servo. We used aluminum, due to its high heat conductivity and low cost. The aluminum was bent by hand and cut using pliers to fit the measurements designed. Materials are scarce, so our team sought to use readily available and lightweight materials like wood that could withstand ambient heat and reasonable loads. The woodworking was done by using tools (Saw, Tape Measurer, Writing Utensils, Drill, Screw Drivers, Pliers) brought by one of the team members using drawn up calculated designs. We used 3D printed parts to construct the valves/gate mechanism to utilize the precise measurements calculated and that it was efficient to custom make the parts. The containers used to hold the pancake batter were the bottles that the mix came in so that the replacement process would be quick.

Challenges we ran into

Ensuring a sufficiently heated cooking surface proved incredibly delicate, as the modification of our sheet metal for our needs caused uneven surfaces with very little contact with the heated griddle surface, extending our cooking duration. Adhesion between the pancake and the aluminum surface proved to be a consistent struggle, as non-stick cooking spray did not perform as expected due to decreasing the heat transfer between the pancakes and the surface.

The first challenge with the control system occurred while developing code and running the stepper motors. Working with the Arduino IDE proved to be inconsistent because the software continuously denied access to the Arduino board for unknown reasons. Once the code was uploaded, the stepper motors (Mercury Motors ST-PM35-15-11C) connected to a motor driver (Qunqi L298N Motor Drive Controller Board) would heat up significantly and smoke after minor use. We then switched to using Parallax servos which simplified the code development and proved to work efficiently and effectively.

In the final testing stage, there was an issue that the batter would thicken as time progressed, the weight of the containers proved to be too much, and the Arduino's timer proved to be inaccurate. The thickening problem was addressed by manually squeezing the container while the gate was open, re-shaking the container, or replacing the container with a new one filled with fresh batter. The overhang piece of wood containing the gate mechanism and the containers could not effectively support the weight of the before mentioned items. The wood would bend as more than one container was added and allow the batter to be released from the containers when the gate mechanism was closed. This issue was fixed by only using one container because there was not enough time to allow the construction of proper support beams to help dissipate the weight. The Arduino's timer was set to allow the pancakes to cook for 10 minutes before transitioning to the next stage, but after each loop of the code, the transition between stages surpassed the ten minute mark more and more.

Accomplishments that we're proud of

We found an equation of flow rate which included a viscosity equation. Using this equation we determined the size of the drill bit and gate size required to allow the batter flow as expected. We found the viscosity by its mass/volume and plugged it into the Poiseuille equation which gave the flow rate of the pancake batter given different nozzle sizes. That the process was automated up to a certain extent and was able to produce two pancakes every ten minutes after the initial setup. For the mechanical side of the project, we repeatedly came up with many mechanical designs involving linkages and cantilevers, incorporating all the functions into a single structure. For the software side of the project, we programmed the Arduino effectively to run on a loop to control each servo to work as expected (turning to certain degrees exhibiting specified rates at measured time intervals).

Skills we learned

Arduino programming, Additive manufacturing, fluid dynamics, heat transfer, food science.

Results

Recorded results using video, images, timed tests, and written analysis. Overall, the product worked as expected but did not meet project requirements of automation and pancake quality. Would not recommend moving forward with the prototype unless major revisions are made to the current design. Therefore, the team is planning on moving forward with manufacturing and designing the system with the robotic arm.

Computer Vision:

The proposed hardware design for the computer vision system works because it meets all the functional and non-functional requirements set by the potential users. The software design of the system is what needs to be tested to effectively determine what the most efficient algorithm design is. The analysis will be re-evaluated when the prototyping is starting. The current strengths of using method one is that advances the team member's current engineering and mathematical skills and is a reliable technique of ensuring the pancakes will be flipped on time. Another pro of using this method is that it is inexpensive comparable to the other options available. The weakness of the method is that there will be a large learning curve. Brett plans to overcome this challenge by working with his mentor, Alexander Stoytchev. Another con that needs to be addressed is limited amount of storage on the camera that needs to be replaced after every four hours of use.

Electrical and Mechanical Systems:

A number of previous designs and ideas have been evaluated for the electrical and mechanical systems of the multi-purpose arm. The evaluation process has consisted of considering pros and cons to proposed solutions, some prototyping in the form of drawings and sketches. We arrived at our present design (see Figs. 2 and 3) through these means and also through consultation with out faculty advisor. We observe that while we presently have a good design on paper, further testing is needed with physical prototypes. It is obvious that further refinements could be necessitated by our findings from doing so.

Specifically, it may be advantageous to mount the THOR arm from above rather than from below the griddle, to take advantage of the degrees of freedom of the design better. Also, we intend that an oscilloscope and multimeter be used to test the circuit performance of our project. This is especially to address issues relating to signal noise, proper power delivery, and proper connections being made.

Key strengths to this design of the electrical and mechanical systems are safety and simplicity. It is both convenient and safe to have all electrical grounds connected to one common conductor. It is also much more simple from the client's perspective to have only one cord to plug into the wall and know that the machine is powered and grounded. The cable management techniques and the principle of keeping as many electrical connections and components inside of a housing also works toward that purpose. For the user, operation is as simple as plugging it in, filling it with pancake batter, and selecting the specifications of their pancakes. From our perspective, construction of this apparatus is relatively simple as well. Most of the electrical components are available for purchase from vendors and need very little modification. The situation is similar for much of the hardware. This simplicity is aided by the modularity of the major components of our system (it is not necessary to build a power supply or griddle from scratch, for instance).

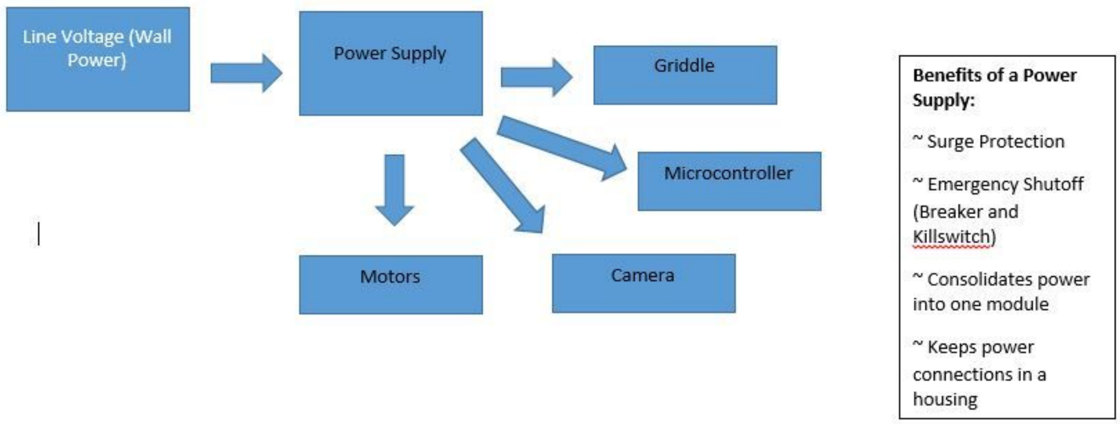

Fig.6 Basic power flow, showing the advantages of a commercially-available power supply

With all of that said, there are indeed certain disadvantages. The flip side to using pre-made electrical components is that matching the characteristics and dimensions to our purposes can be a complex task. Most components come in standardised ratings for voltage, power consumption, etc. so care must be taken to combine everything into a coherent system. The same may be said for the physical dimensions of components. A particular concern is the power supply, because as can be seen from Fig. 3, there are a variety of DC and AC electrical sources that must be available. This may require some additional power conversion. Indeed there are other potential issues for this proposed but as the project progresses those shall be dealt with in turn. A chief advantage the proposed design has is that it is easy to modify, as the modularity of major elements allows for the addition, subtraction, and modification of almost every component.

Embedded Systems:

For the design for the embedded systems, there has been a lot of research on chips that will be powerful enough to handle the systems that our design has and that will integrate with the components that we are going to be using for this project. The embedded systems engineer has decided to chose the Avnet Ultra96 for the FPGA board. The pro of the board is that it is designed to accelerate the development of pin layout for the engineer's desire and it also has the ability to have usb inputs, which allows the camera we are using to be interfaced easier. The con however is that the processing speed is not as fast as more expensive options. However, it will work for our team's requirements.

3 Testing and Implementation

3.1 Interface Specifications

Robotic Arm:

For the physical testing of the robotic arm, there is only a finite amount of hardware and software which will be required to test the device's performance. Various components will need to be connected to the robotic arm in addition to a simple segment of code to test the motions in which the arm is capable of performing in addition to the amount of weight it can realistically maneuver.

Being able to visually capture the capabilities of the robotic arm when operating will be key in testing the functionality of the device.

Computer Vision:

The computer vision system will require interfacing between the camera and the FPGA. Testing needs to be done to ensure that image processing can be read from the camera every 0.5 seconds at a maximum and be analyzed by the FPGA.

Electrical and Mechanical Systems:

The user will interface with this machine in two main ways. The first is to add batter to the batter bowl by the griddle and then to clean said tank when done. Ordinary soap and water works fine for cleaning the machine. The second way in which a user interfaces with this machine is the pancake controls. Simplicity and ease is emphasized by this design. A large rocker switch with indicator LED turns the machine on and off. The griddle power is controlled separately by a similar switch. Griddle temperature is adjusted by a large ergonomic knob attached to a potentiometer. The controls are clearly and appropriately labelled for easy identification. We test that these things meet our requirements by asking people who are not a part of our group and who are not familiar with our project to interact with the controls and batter system. Then we observe their reactions and listen to their opinions regarding the experience.

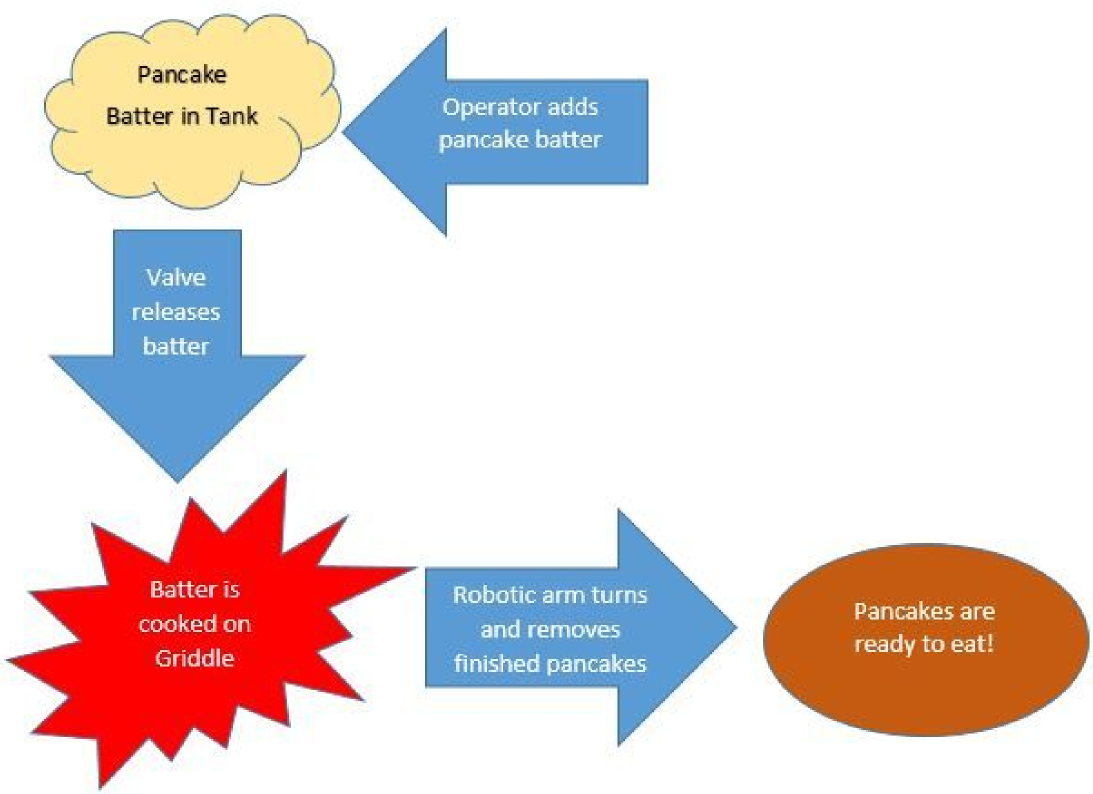

Fig. 7 Product flow through system

Embedded Systems:

For the testing for the FPGA will be mainly be through the program we use for the programing and writing of the code on the chip. The programing of the FPGA needs to be tested because it will have to be able to take inputs from a component and do calculations and if the way the FPGA takes the input is wrong then the output to the arm will be wrong. The software that will be coded on the chip will also need to be tested so that the calculations will be correct and precise. We will use a test bench program to test the input signals and will show output signals. We can set the inputs the way we want in this program and see if the output is correct from the inputs that we entered.

3.2 Hardware and software

Robotic Arm:

In order to properly test the robotic arm before it can be implemented into the final design, several components will be required to test the functionality of the arm. Most of the required components are already owned by members of the team or can be purchased through an online vendor.

Hardware used for testing:

- Power Supply
- Arduino
- Motor Shield
- Electronic Scale
- FPGA

Software used for testing:

- Arduino IDE
- Vivado (used for programing and testing FPGA)
- SDK

Hardware Descriptions

The power supply provides power to the motors which are used to power the robotic arm. While for testing purposes it would be ideal to have a variable power supply it is not required and a power supply capable of 9 to 12 Volts DC would be sufficient depending on the size of the motors.

The Arduino microcontroller will be used to program a series of movements for the arm to follow in order to test the capabilities of the device.

The motor controller will allow for the signals created by the Arduino microcontroller to drive the motors as the Arduino all by itself does not have enough power to drive the motors which control the robotic arm by itself.

The electronic scale is a great way to measure the weight which will be subjected to the robotic arm.

Fig. 8 Avnet FPGA

The FPGA is good for processing incoming inputs and outputs what the arm should do. Also, the FPGA will be able to interface with the GoPro that we are using because of the input usb slots. The output pins will go to the Arduino.

Software Descriptions:

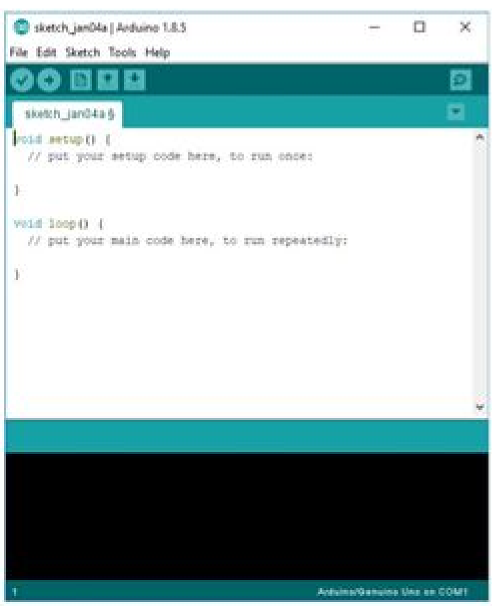

Fig. 9 Arduino IDE

The Arduino IDE (Integrated Development Environment) is a software that allows the team to program commands to the Arduino microcontroller. This is how we will program the robot to perform a series of motions to test the physical abilities of the robotic arm.

Computer Vision:

The computer vision system will require a GoPro Hero 3 to accurately transmit high definition data at a high frame rate per second.

The software being tested will be hosted on the FPGA and will need to utilize image processing to send commands to the arm. The programming language that will be used is Python so that the program can perform high level functions. The correct libraries will be installed onto the FPGA so that the pipelines can interpret the data signals.

Vivado

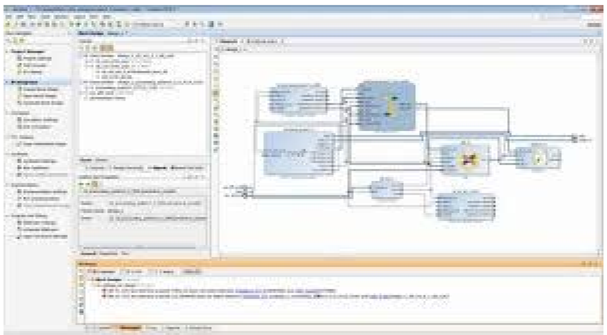

Fig. 10 An example of Vidado being used

This program allows you to design and and program the FPGA with the hardware it will be using. Also, it has a testing method call test bench.

Vivado Test Bench

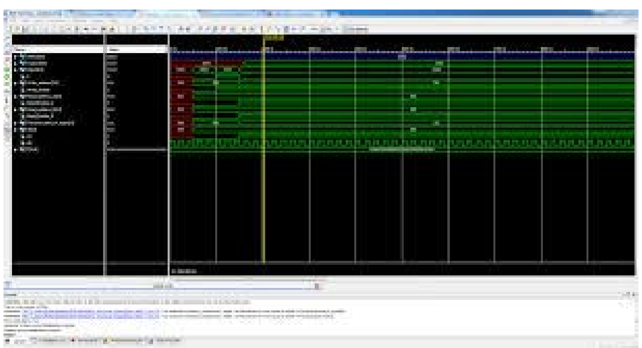

Fig. 11 Vivado test bench software

This is a testing program that is in Vivado. It is used for the testing of the inputs and outputs of a specific module in the pipeline of the FPGA hardware.

SDK

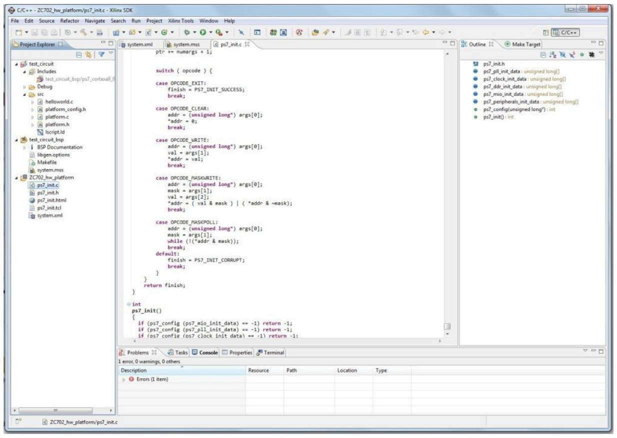

Fig. 12 the SDK used

Once the pipeline is made we export it from vivado to the SDK for the making of the code that will be programed on the FPGA. This code will be the computer vision.

Electrical and Mechanical Systems:

Hardware Used for Testing:

~ power supply (see above)

~ plywood

~ meter stick

~ calipers

The power supply is described in an above section.

A piece of plywood provides a durable base for building prototypes on top of and also for testing and troubleshooting the finished product.

A meter stick is useful to us for measuring components and verifying that they meet the dimensional requirements we have for them. It measures distance using the metric system.

There are not software considerations for the purely electromechanical elements of our design, other than that the electromechanical systems must be operational to fully test the software.

3.3 Functional Testing

Robotic Arm:

The robotic arm portion is being tested on its mobility, ability to maneuver in a precise and fluid way, and the weight it can carry. For testing the range of motion the robotic arm can produce, human commands transmitted through the Arduino microcontroller directs the position of the motors controlling the robotic arm. By having the motors operating at only a fraction of their potential speed, the team is able to reliably determine the capabilities of the robot. This test does not require the documentation of the max range values the arm is able to perform, instead team members observe whether or not the arm is capable of performing the same degrees of motion used to make and plate a pancake. The next test is designed to test how fluid the robotic arm can perform actions. By playing with the Arduino IDE and how the program interacts with the motor controllers which in turn affect the motion of the motors controlling the robotic arm, team members are able to determine not only how smooth the robot can perform any desired task in addition to the speed at which the task is completed. In order to get the correct speed to perform the desired task, utilizing the Arduino's analog ports is required. If the arm needs to gain speed to perform a task then a higher analog value may be sent to the desired servo. The desired speed of these components will be determined by testing and observing the system once the physical setup is complete. The final test involves whether the prototypes in addition to the pancake being cooked can be supported by the robotic arm. Luckily, the robotic arm we are constructing has supporting documentation which includes the maximum payload the arm is capable of carrying. By measuring the weight of the prototypes being added to the robotic arm and by knowing the weight of a pancake the team is able to test if the arm is capable of the additional features the team is opting to add on. In the case of this arm, the additional weight on the arm may not exceed 750 grams before counterweights will be required. A lot of the arm testing requires a lot of observing on the groups behalf as the system has a datasheet which supports that the arm can function correctly in ideal situations, however, the way we are incorporating this arm is not ideal, and as a result corrections to the system are being anticipated.

Computer Vision:

On Computer:

The software program for the computer vision system will be tested by holding a camera connected to a laptop and verify whether the algorithm detects when a pancake should be flipped. To test this a pancake will be filmed that is cooking and when it should be flipped it will be determined if the program outputted that the pancake should be flipped and the direction that the arm needs to go for the flipping of the pancake. Once this is able to be accomplished and a perfect pancake is made, this code will be put on the FPGA for further testing.

On FPGA:

The code will then go through integration testing on the FPGA because the inputs and outputs will change because of the pipeline. We will use a testing method called test bench that shows what is inputted and outputted on the hardware side. Then once the FPGA can get the input to the specific module (Computer Vision module) we will switch to the SDK for the development of the code which will take the input and then control the output. Once the output of the code looks good we will run another test bench to test both the inputs and outputs of the computer vision program and make sure that the outputs will be correct for the Arduino.

Electrical and Mechanical Systems:

The electrical system is tested with a multimeter and oscilloscope to ensure that the expected electrical behavior is found at each node in the circuitry. This includes voltage level, power consumption, and signal integrity. We need to do this testing because the components that we are using have a specified voltage that they need and going over that could start a fire or ruin equipment. Also, this would prevent issues such as short circuits, interference, and other undesirable effects. The interactions between the electrical and mechanical systems is tested by a few key evaluations. Firstly, wires and cables must not be loose and in the way of the moving parts, nor should their harnessing impede the motion of the arm. Secondly, it must be demonstrated that the motors work properly. This can be shown by observing the motors move or not according to the appropriate signal. Thermal dissipation must be kept in check to avoid overheating. Precautions are taken to account for this, such as heat sinks and proper ventilation. A thermometer may be needed to get a more accurate determination of this situation.

Embedded Systems:

The functional testing will be if the FPGA can handle all the inputs and output them correctly. The FPGA having enough processing power to handle the components that we are using while running the code for computer vision. The testing for the software side that we will be using are callouts in the code that is running on the FPGA and showing us what is going on (Most of the testing for the software side will be through the computer vision testing), but mostly the testing that will be going on in for the FPGA will be a test bench to show the inputs and outputs are correct and that the pipeline that is set up is working for inputting the data and outputting the data correctly. The inputs will be from the camera and the outputs will be to the Arduino.

3.4 Non-Functional Testing

Robotic Arm:

The nonfunctional testing surrounding the construction of the robotic arm is purely aesthetic. The arm must be easily incorporated into existing kitchens in an easy and efficient way without ruining the current kitchen setup. Testing is done by meeting with several individuals unrelated to the team and getting their input on the device. Specifically the are being asked whether this product would fit in their current cooking setup and if they see the robotic arm as another appliance for their kitchens. While a large portion of this test will be done purely by listening to the subjects inputs, the inclusion of a survey card will also be used. The card will include several statements asking the subject to input a value between one and five where a value of five is considered strongly agree while a value of one is associated with strongly disagree with the statement. Some of the statements on this card include, but are not limited too; this device fits nicely within a home kitchen environment, this product looks in appearance like kitchen appliance, and I would be willing to incorporate one of these devices into my own kitchen if given the opportunity. The survey card would also have a section where people could leave their comments about the device. This is an important test as clients will need to feel that our product is not intrusive to their space, but rather enhances it. Having a survey group to understand whether this was accomplished is vital to the products success.

Computer Vision:

The computer vision system will need to be reliable enough to constantly send images of the griddle. This would be tested by doing duration tests of how long the camera can continuously run while the FPGA processes the data at the same rate. The process needs to be scalable to relay detailed information about multiple pancakes within the set field of vision. This will be tested by starting with one pancake and adding additional pancakes until the embedded system does not receive enough details of each pancake to be successful. Once completed, the computer vision system should require little to no maintenance after the final testing stage is done. We will also set up a timer on the FPGA that will time how long it take to process this information and output it. That time will reveal the need to speed up the program or make acceleration adjustments on the FPGA hardware setup or not.

Electrical and Mechanical Systems:

Testing reveals, among other things, if the overall appearance is aesthetically pleasing to many people. In addition, the user experience with the controls and operating the machine is surveyed. Further, it is tested that people find it easy to clean. This is done by finding a group of self-selected volunteers and asking them to respond to a series of questions after allowing them to interact with the machine. Then the survey is taken into consideration and changes are made that please everyone.

Embedded Systems:

The big test for this is if it can do everything fast enough so that pancakes don't get burnt and that everything runs smoothly so that every output is correct. This can be done by by setting up a test bench that takes information in and shows what will be outputted. While it is taking information in it can be observed if the inputs are all correct and none are wrong or misleading. Also, for the outputs to be correct we can have pictures of bubbles in pancakes to test the output signals. While this test is running we will have a timer running that will test the time of the input to the output and if it isn't what is needed, there will be software speed ups by getting rid of time consuming code, or make hardware speed ups by accelerating the processes were we can of the pipeline setup.

3.5 Process

Robot Arm:

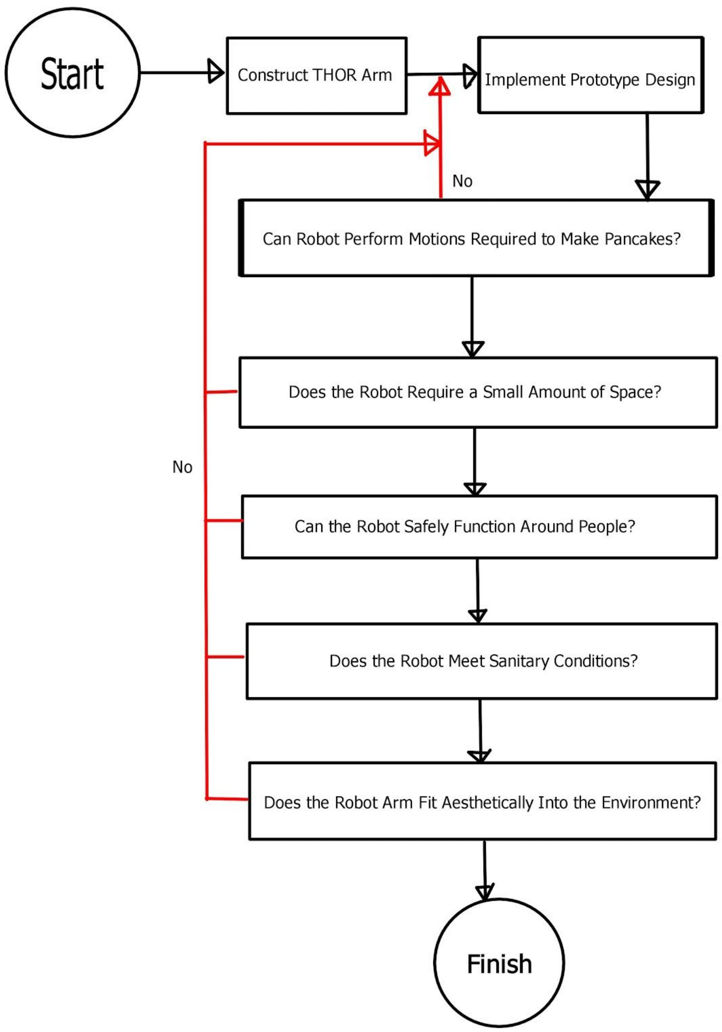

Fig. 13 Flowchart of testing

The methods used to test whether or not the robot is capable of producing a pancake and if the robot met the aesthetic requirements were discussed in a previous section of this document and will not discussed here. Determining the amount of space the robot is allowed to function in has not been currently defined. The team is currently constructing a defined amount of space in which the robot will be required to function in. A box with the volume of the desired space is then constructed. As long as the robot doesn't make contact with the box while operating it passes the space test. The team is currently observing the function of the robotic arm and examining the potentially harmful effects the robot's process might have on humans within the vicinity. For future tests having humans interacting in the same environment will be implemented and observed. Any harmful tendencies the robot shows in the process will be fixed. When it comes to determining if the robot meets sanitation requirements, the team is reviewing the sanitary codes of restaurants and making sure the robot meets all of said requirements as a kitchen appliance.

Computer Vision:

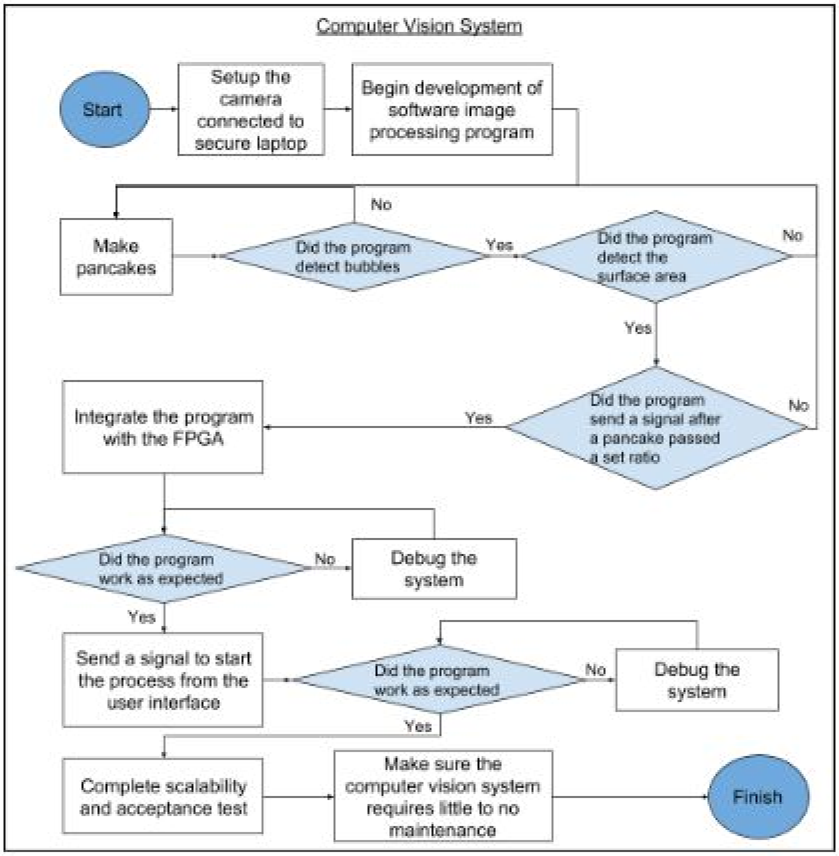

Fig. 14 Computer vision testing flowchart

Electrical and Mechanical Systems:

Testing methodology for this section of the machine proceeds as follows:

1. The functional aspects are tested first, being that they are fundamental to the project.
    a. Electrical components are tested first, since they move the mechanical parts it is natural that they should have precedence.
        i. Electrical safety (including shock and fire hazards) is addressed once the basic circuitry is in place.
        ii. Proper electrical characteristics are tested for each component to verify that each is functional before going into a larger circuit. A power supply and multimeter is used for this.
            1. If a component does not function as needed, it is exchanged for a different one which is tested in the same fashion. This is repeated until a satisfactory component is found.

iii. The components are assembled into the circuits dictated by the schematic using a breadboard, power supply, jumper wires, and necessary discrete components.
iv. Testing with an oscilloscope and multimeter is conducted to verify the desired circuit behavior is observed.
1. If changes are needed, the circuit is adjusted accordingly until the functionality being tested is achieved.

b. The mechanical pieces are tested.
    i. Each component is assessed for appropriate durability.
    ii. Each component is tested for proper dimensions.
        1. For many components, this may be done by simply ensuring that they fit together with certain other components. For others, it may involve taking measurements with a meter stick or calipers.
c. The entire system is assembled and troubleshot at a holistic level.
    i. Th overall functionality may be assessed by evaluating the pancakes produced by the machine. Namely;
        1. Does the machine move according to the programming it is given?
        2. Does the machine allow batter onto the griddle?
        3. Does the machine heat the griddle adequately (not too much and not too little)?
        4. Does the machine allow the batter to cook into a pancake (neither prematurely ending cooking nor overcooking the pancake)?
        5. Does the machine flip the pancake?
        6. Does the machine exit the pancake once it is done cooking?

2. The non-functional aspects are tested. While important, the implications of aesthetics, user-friendliness, and ease of cleaning are determined by the situation created by implementing the functionality of the mpARM.
    a. With a functional prototype, people from outside our group are invited to assess the overall appearance, ease of use, and ease of cleaning of the machine. It is desirable that they should give feedback to questions such as:
        i. Would you eat pancakes made by this machine?
        ii. Would you consider having this machine in your home or business?
        iii. Do the controls feel intuitive?
        iv. Do you feel that this machine is easy to clean and care for?
        v. Is this machine easy to use?
        vi. If this were a commercially available product, would you consider purchasing one and why?
        vii. Do you feel that this machine has a nice appearance? Why or why not?

Embedded Systems (Flow Chart):

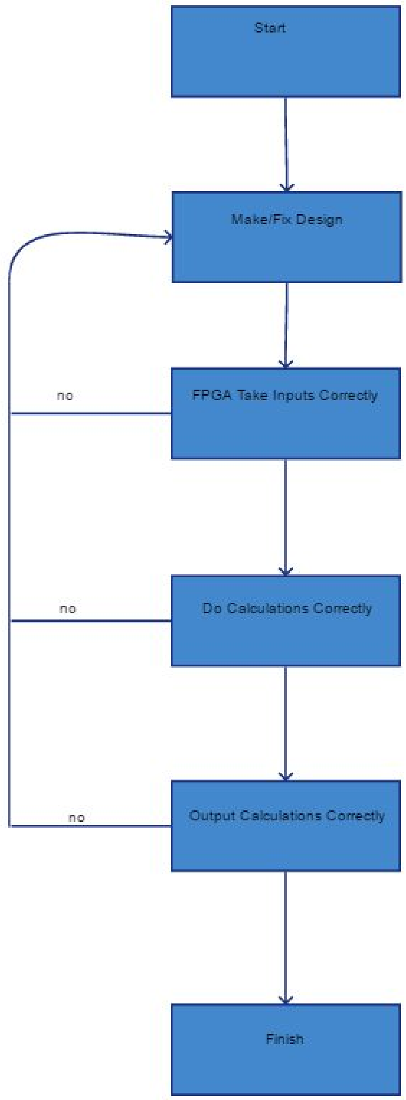

Fig 15. Embedded systems testing flowchart

3.6 Results

Robotic Arm:

There have been no results for testing the printed robotic arm as physical construction of the project is limiting as cost constructing is reserved for later into the first semester and the majority of the second semester. A small prototype was made out of cardboard using the dimensions of the proposed robotic to clarify the ranges of the robot. These results played a part in making the switch to mounting the arm from above on a support structure.

Computer Vision:

When pancake recipes were tested, the team took in detailed information about the recipes being used and the information we received about each of the cooked pancakes and wrote down comments on what went well, what needs to change, and what the next step will be. The team also developed the recipes and cooked the pancakes whereas a team member was in charge of recording the process of cooking the pancakes and recording information. The team determined whether the pancake met expectations and requirements for presentation and taste to be considered as a viable product. In the end, the team used a wide variety of ingredients to create a good pancake recipe and found out that cooking on the electric griddle proved to be more reliable and produced better quality pancakes. The team members built a stand out of cardboard to hold the recording device above the pancake cooking area.

The computer vision program is currently being developed utilizing hough circles to detect the attributes of the pancakes being cooked and the presence of bubbles seen in the pancake. To test the program the developers are using the video files of the recorded pancakes. The next step of the process is to use the program employing a real time image stream and determine if the program is still as accurate. Then the program will be integrated with the FPGA so it can run without the assistance of a laptop.

Electrical and Mechanical Systems:

The physical testing has not yet proceeded. However, ideas have been theoretically tested to arrive at the present design. This is in terms of feasibility, safety, and other practical matters.

Embedded Systems:

The team has received the chosen FPGA board and the embedded systems engineer is utilizing winter break to implement his pin layout and start implementing planned pseudocode. More results will occur during the implementation stage next semester where the FPGA will be relied on more to combine the modules together.

Modeling and Simulation:

While much of the code remains untested at this point in the design process, a good portion of the robotic arm has been modeled and 3D printed (see Figure THOR Robot Arm and Figure THOR Subsection below). Additional components such as the arm attachment are currently being developed, but have yet to be finalized and modeled. Aspects of the project such as the fixture acting as both the robot's environment and mounting mechanism have been sketched and discussed, but because these ideas are early in their design state and have not been finalized no digital render has been created to represent these aspects of the project.

Logical analyzation has been used where simulations and modeling are currently impractical this early in the design process. One such situation involves the fixture designated to hold the robotic arm in place. For the final product it was determined that the arm should be mounted above the the workspace as opposed to being placed on the countertop adjacent to the hot plate. While some aspects of this fixture have been modeled through the use of sketching other aspects of the fixture remain uncertain until physical testing can begin such as whether or not the robot will have the linear capability to interact with all the desired components. Since it is yet uncertain the exact range the robot will need to have, it was determined on a purely logical level that a linear rail might be necessary depending on the final environment setup.

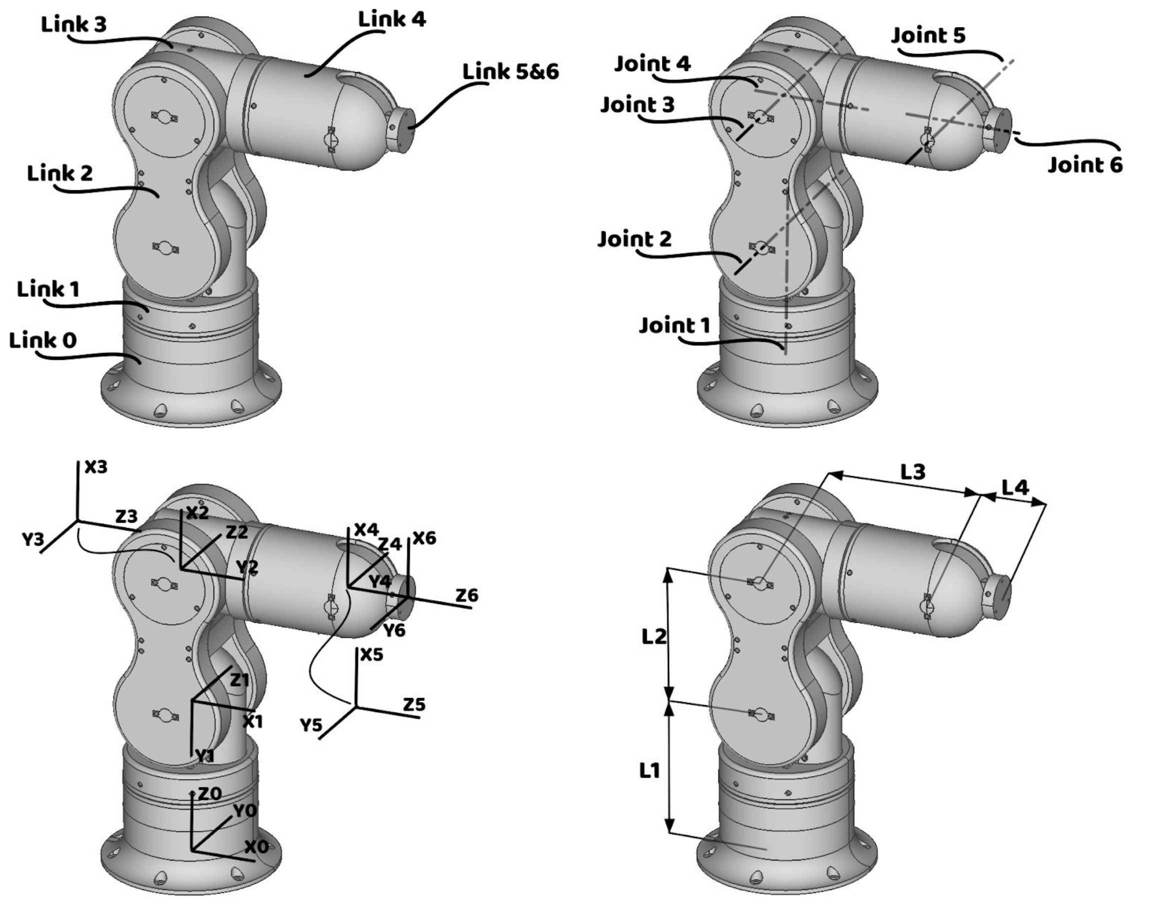

Fig. 16 THOR Robot Arm

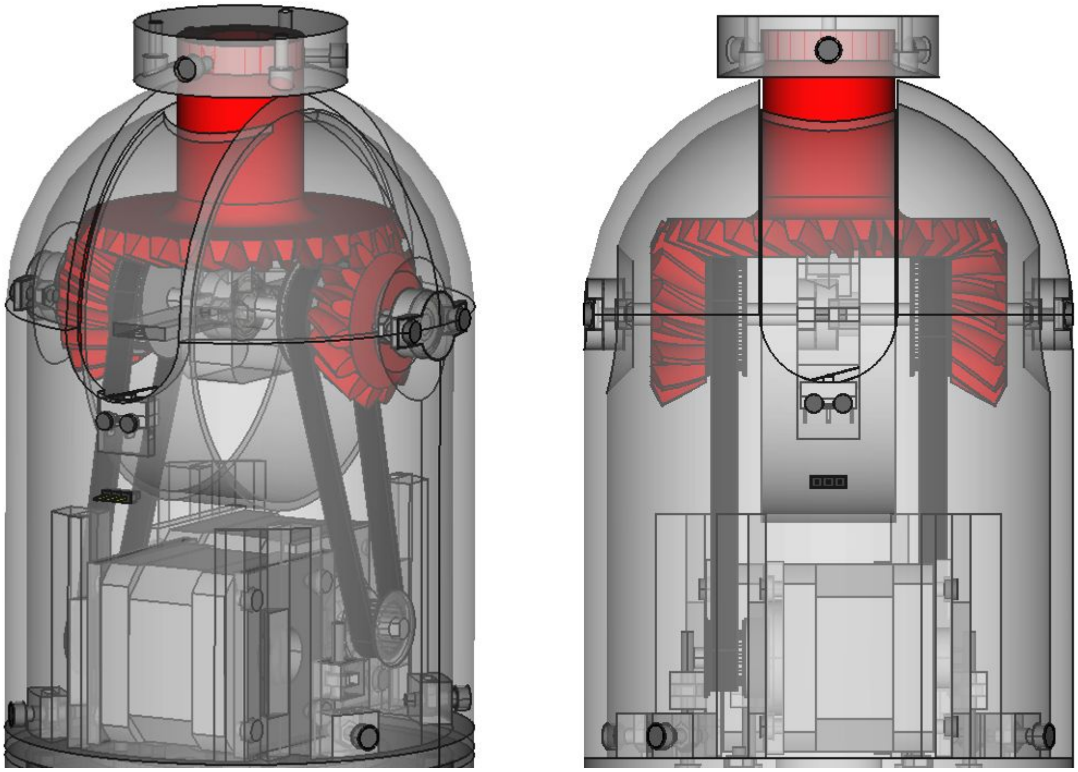

Fig. 17 THOR Subsection

Implementation Issues and Challenges:

While testing has yet to commence involving the entire system, it has become apparent through subsystem testing that several issues may arise in the future. Initial testing of the computer vision system yields a positive result when distinguishing a pancake from the surrounding environment, but currently has difficulties recognizing the bubbles forming on the pancake's surface which indicates that the system should flip over the pancake. Implementing a computer vision system capable of identifying that a pancake has been properly poured in addition to knowing when to flip the pancake will be difficult. A potential challenge associated with the robot arm is whether or not it will have the capability to move quickly and precise enough to both flip a pancake in addition to removing the pancake from the surface of the griddle. The robot arm documentation supports that it has the potential to perform similar tasks, but there is no resources confirming it can perform exactly what we are demanding from it. If the arm is incapable of accomplishing one or both of these tasks than other devices will need to be constructed to work alongside the robot arm as a workaround solution.

Our system is comprised of multiple smaller subsystems which act as communication channels between the inputs and outputs associated with the full system. Once challenge our team anticipates is the reaction time of our device. Between software communications staring from the computer visions camera proceeding to the FPGA which then communicates to a microcontroller and finally to the motors which control the physical system, there is a concern that there is the potential of a less than desirable delay especially when it comes to the safety systems. While this delay has yet to be produced it is definitely something the team is thinking about ahead of time should this implementation issue arise. On a more general basis, another issue revolved around product implementation is making the system easily installed in already existing environments. Mounting a relatively large arm in an already existing kitchen in such a way so that the device receives power while being able to correctly function in the workspace and not being an obstruction is a challenge our group will need to overcome if this product is to be implemented.

4. Closing Material

4.1 Conclusion

In conclusion, the team is developing a mechanism able to optimize efficiency and consistency of modern day cooking and save consumers time. The mpARM will be able to make pancakes at the touch of a button and on completion serve food on a platter. This product is implementable in modern day smart homes and will increase the reputation and market value of a restaurant. As the project continues the team will gain insight in the project progress. When building the product, a comprehensive list of resources used to develop this project will be compiled. This list will grow into the second semester. In the end a device will be developed which both solves the increase in restaurant costs while providing everyday consumers with the ability to elevate themselves from the pains of cooking and instead focus their time on more meaningful tasks.

4.2 References

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Reference 7: https://www.youtube.com/watch?v=qJnvUReDUWE

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4.3 Appendices

Fig. 18 Arduino Microcontroller for THOR arm testing

Fig. 19 Arduino Microcontroller Motor Driver for THOR arm Testing