PCMI: Playing Card Manipulation Initiative

Vacuous, Inc.

Prepared by Alexis Carey, Aurelia Kornheiser, Lila Sargent, and Tovahn Vitols

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Introduction

This report addresses the creation and development of Vacuous Inc.'s CS 2210 final project: Playing Card Manipulation Initiative (PCMI). This includes details of the project, project development, budget along with cost analysis, final code, and conclusion.

At its base this project continues a long tradition of integrating technology into various games and pastimes. The PCMI project involves three (3) major components: a card identification model, a card manipulation module, and a game module. The card identification model consists of a camera connected to an AI model that reads and forwards its classification. The card manipulation module consists of a robotic arm that can move cards between the deck and playing field. The game module consists of the UI and backend for game mechanics and logic. While Vacuous, Inc. has chosen to focus on implementing a game of blackjack, PCMI's core functionality can easily be adapted for any card-based game.

This project overall has been a large amount of work and allowed each team member to develop as a computer scientist. Vacuous Inc. believes that we have been able to create a very interesting and unique product, and hope you believe the same.

Definitions, Acronyms, and Abbreviations

PCMI	–	Playing Card Manipulation Initiative
MVP	–	Minimum Viable Product
Pi	–	Raspberry Pi
UI	–	User Interface
Arm	–	Robotic Arm Component
Shuffler	–	Card Shuffler Component
Game Unit	–	The module containing the Arm, Camera, and Raspberry Pi
GPIO	–	General-Purpose Input/Output
HTML	–	Hyper Text Markup Language
CSS	–	General-Purpose Input/Output

Project Details

Project Structure

This project has been structured into an MVP, core goals, and various stretch goals.

MVP

The MVP for this project was a robotic arm that can pick up and move playing cards. The arm would be 3d printed and utilize servos for its movement. Cards would be picked up using a tube connected to a vacuum pump mounted on the robotic arm. A Raspberry Pi would be used to control all aspects of the mechanism. Vacuous, Inc. has been able to successfully develop the MVP that we designated at the beginning of the semester.

Core Goals

In the start, our core goals were to create the MVP, create and utilize a camera module and machine vision to determine the value and location of playing cards on the play field, manufacture a mechanism that takes a deck of cards and shuffles it, manufacture a mechanism that will deal one card from a deck, and create a web-based user interface for the players to choose to hit or stand.

Vacuous Inc. has been able to complete the majority of these goals. We have successfully created the MVP, a camera module with machine vision, and a web-based interface. Unfortunately, the team was unable to manufacture the Shuffler nor a mechanism to deal one card from the deck, as that would also have been a component of the Shuffler. These goals, however, were not a part of the MVP, and thus Vacuous Inc. was aware that there might not be enough time to implement them.

Stretch Goals

Vacuous Inc. also designated some stretch goals that would make the game more exciting or interesting, although not essential. (although not essential). These were to expand the user interface to support betting, possibly including physical poker chips, allow blackjack hands to be split or doubled, clean up presentation of project, and expand the game capacities to allow for other games. These goals were not believed to be realistically achievable, which Vacuous Inc. mentioned in their Project Proposal.

Due to time constraints, Vacuous Inc was not able to implement any of these goals.

Technical Writeup

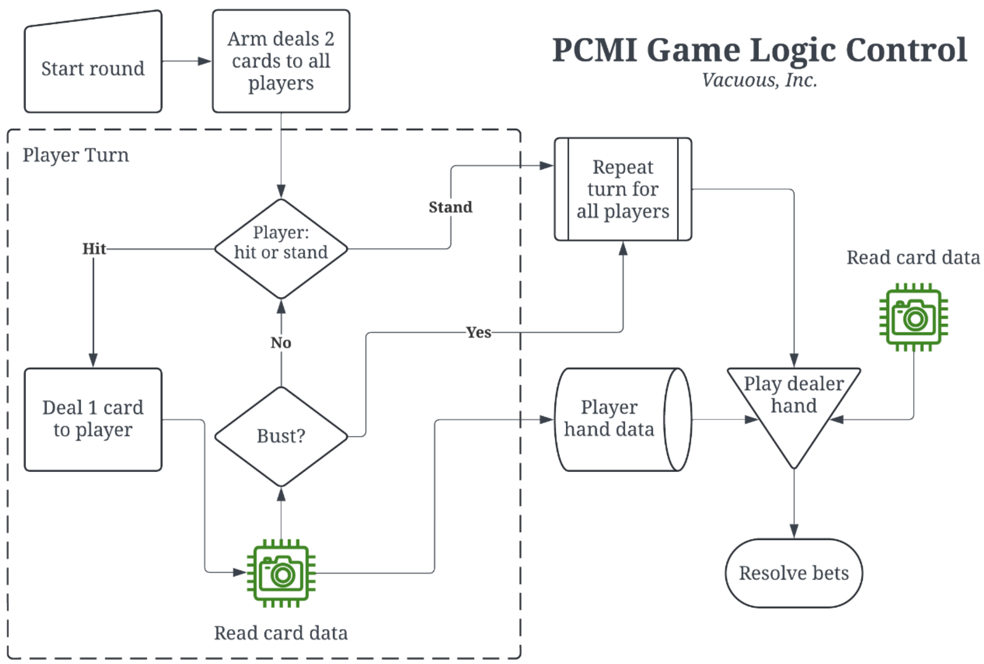
Software

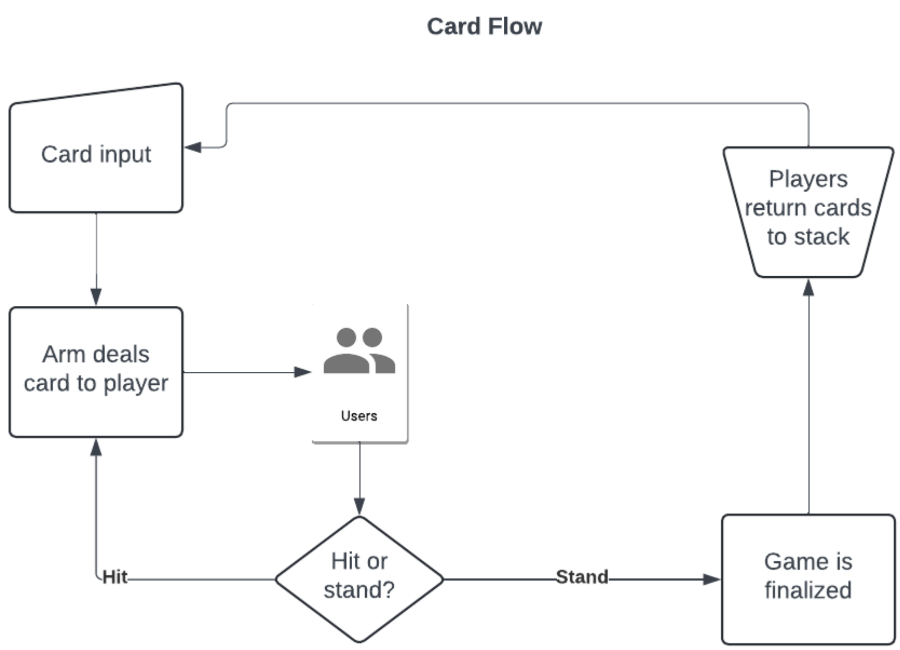
Vacuous, Inc. plans to primarily utilize Python for software. Servos and other mechanical components will be controlled using the same GPIO library as is used for labs. Evan Juras' OpenCV Playing Card Detector (Juras 2017) will be used to detect the suit, number, and location of playing cards. The web interface will be written in HTML, JavaScript, and CSS with a MySQL database. It will be operated with Flask.

Hardware

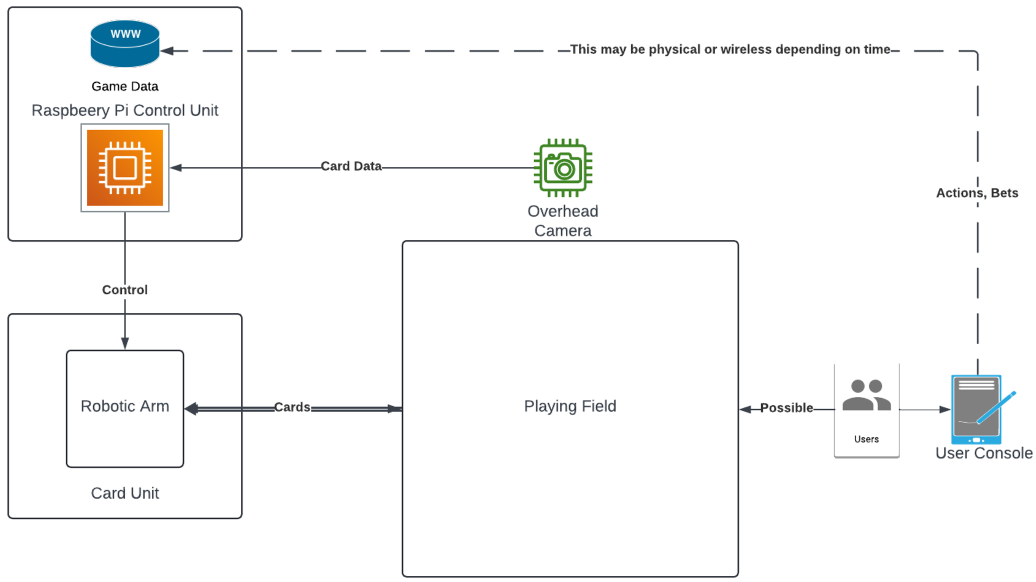
Vacuous, Inc. plans to design the robot arm in Fushion360 and 3d printing the majority of the parts. There will be four points of rotation on the arm, and one more at the base, with a servo controlling each point. The mechanism for picking up the cards will consist of a vacuum pump built into the base and a tube that runs to the end of the arm with a suction cup that will be able to pick up a card. The camera will be mounted to the base of the arm.

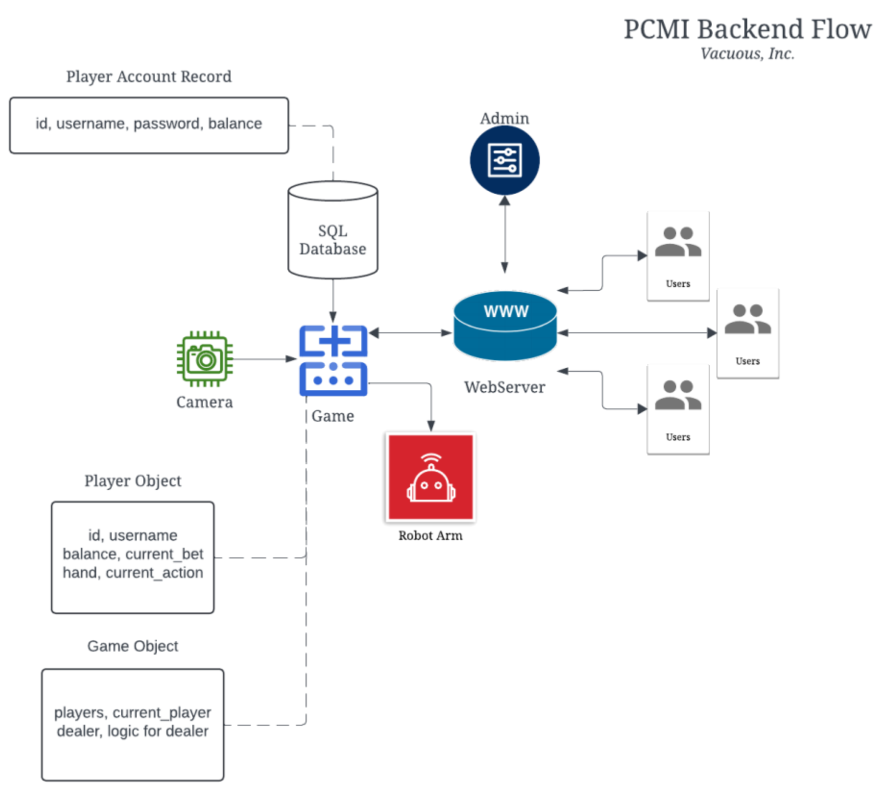
Technical Diagrams

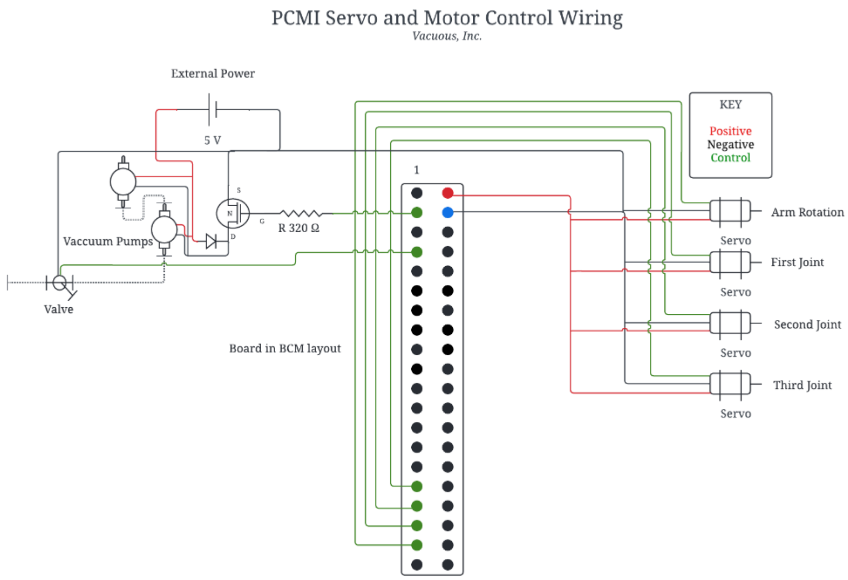


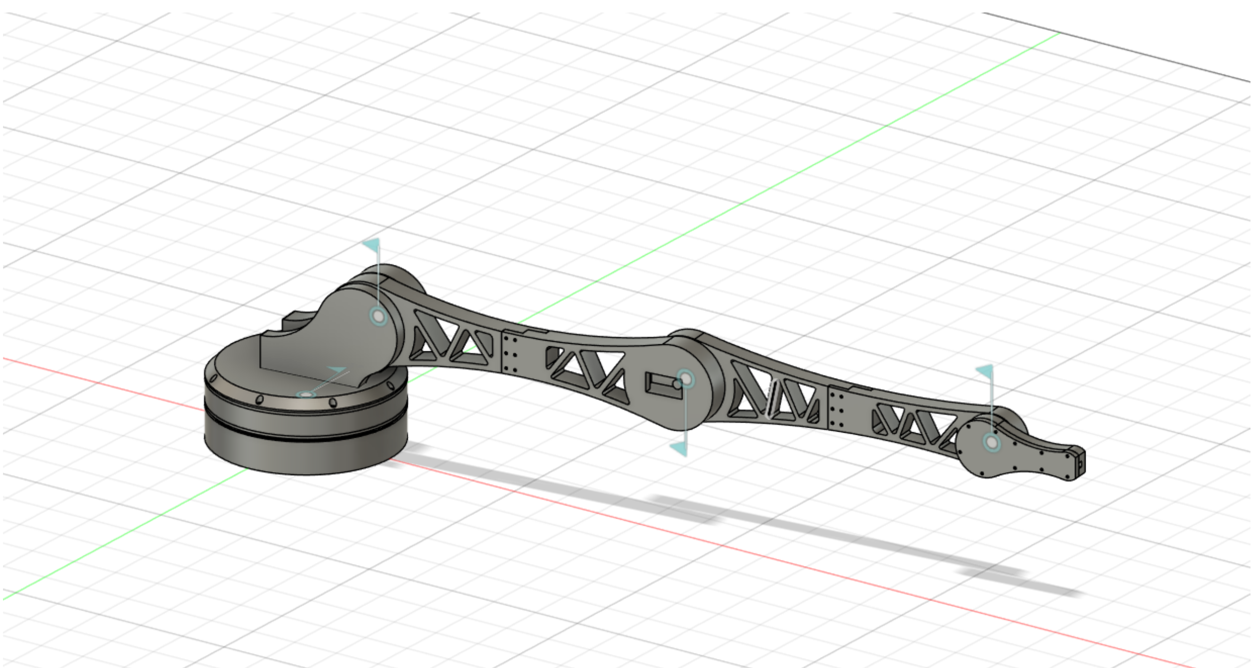


Broad Overview






PCMI Servo and Motor Control Wiring
Vacuous, Inc.
External Power
5 V
KEY
Positive
Negative
Control
1
R 320 Ω
Vaccuum Pumps
Valve
Board in BCM layout
Arm Rotation
Servo
First Joint
Servo
Second Joint
Servo
Third Joint
Servo



Budget

The total proposed budget for this project is $14,024.91. This includes $24.91 for material and $14,000 for labor, as seen in the tables below. It should be noted that this cost factors in the materials we already have, should we have to purchase said parts, this would raise the total cost to $14,214.84.

Estimated Bill of Materials

Part	Total Needed	$/Part	Already Have	Acquire Cost	Total Cost
Servos	5	$12.99	5	$0.00	$64.95
Motor	1	$9.99	1	$0.00	$19.98
Vacuum Pump	1	$7.95	0	$7.95	$7.95
Tubing	2 m	$2.50	0	$5	$5
3d Printing	Unknown	Free	0	Free	Free
Rubber Rollers	4	$1.49	0	$11.96	$11.96
Raspberry Pi	1/2*	$55	2	$0.00	$55
Deck of Cards	1	$5	1	$0.00	$5
Misc. Circuitry	Unknown	------------	Enough	$0.00	~$10
Camera	1	$25	1	$0.00	$25
Fasteners	Unknown	-----------	Enough	$0.00	~$10

*All parts pricing based on Adafruit, Vex-Robotics, or Amazon

Total Cost: $214.84

Total Cost of Acquisition: $24.91

Actual Bill of Materials

Part	Total Needed	$/Part	Total Cost
Servos	3	$ 31.32	$93.95
Motor	1	$9.99	$19.98
Vacuum Pump	2	$7.95	$15.90
Tubing	2 m	$2.50	$5
Rubber Rollers	4	$1.49	$11.96
Deck of Cards	1	$5	$5
Camera	1	$25	$25
Transistor	1	$1.95	$1.95
Pitch 2-pin Cable	2	$0.95	$1.90
Diode	15	$0.15	$1.5
Air Valve	2	$2.95	$5.90
Shipping	1	$11.85	$11.85
Shipping	1	$6.99	$6.99
Non-slip feet	1	$7.48	$7.48
Screws, wires, soldering iron, 4 mini-servos, Alan keys, heat shrink	1	$89.17	$89.17

*This does not count materials that were free, such as 3D printing, or that Vacuous Inc. already had, such as wires and breadboards.

Total Cost: $303.44

Estimated Labor

Role	Hourly Rate	Estimated Hours	Estimated Cost
Project Lead	$50	60	$3,000
Hardware Lead	$50	70	$3,500
Software Lead	$50	70	$3,500
Integration Lead	$50	80	$4,000

Total Hours Estimated: 280

Total Labor Cost Estimate: $14,000.00

Actual Labor

Role	Hourly Rate	Hours	Cost
Project Lead	$50	54.25	$2,712.5
Hardware Lead	$50	47	$2,350
Software Lead	$50	31.25	$1,562.5
Integration Lead	$50	91.25	$4,562.5

*Hours are estimated based on the Project Plan below

Total Hours: 223.75

Total Labor Cost: $11,187.5

Cost Analysis

As a whole, this project was less expensive than Vacuous Inc. was anticipating. However, that was mostly due to the lower labor costs. In terms of materials, Vacuous Inc. underestimated the cost by a lot. As the project progressed, the team needed a lot more items such as wires, screws, and other servos. Furthermore, Vacuous Inc. did not take shipping into account, which was a non-negligible amount.

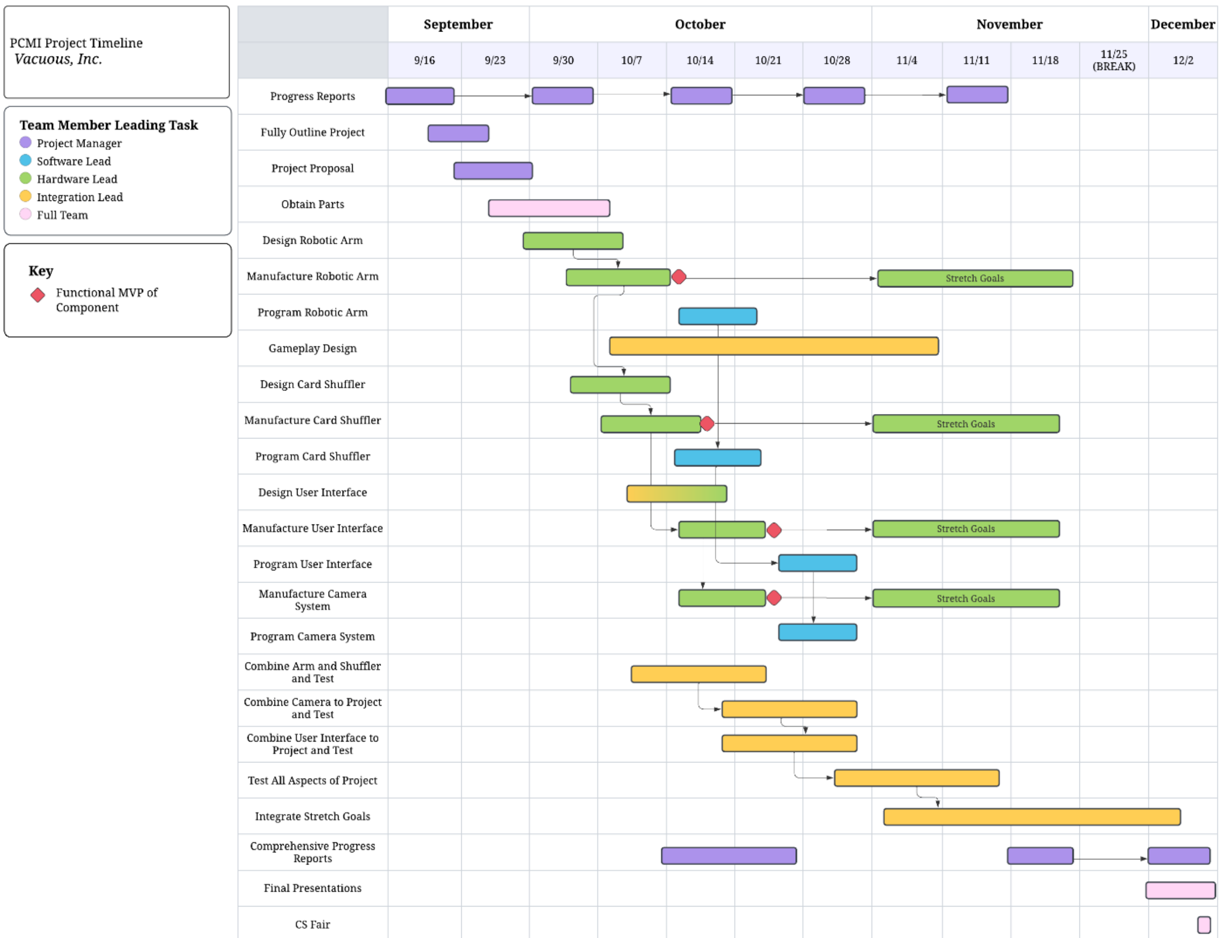
In terms of labor, the team, on average, spent less hours working on the project than anticipated. This, however, was mostly due to the Hardware and Software Lead.

The Project Manager was only a couple hours under the estimated time, and the Integration Lead was actually a decent amount over.

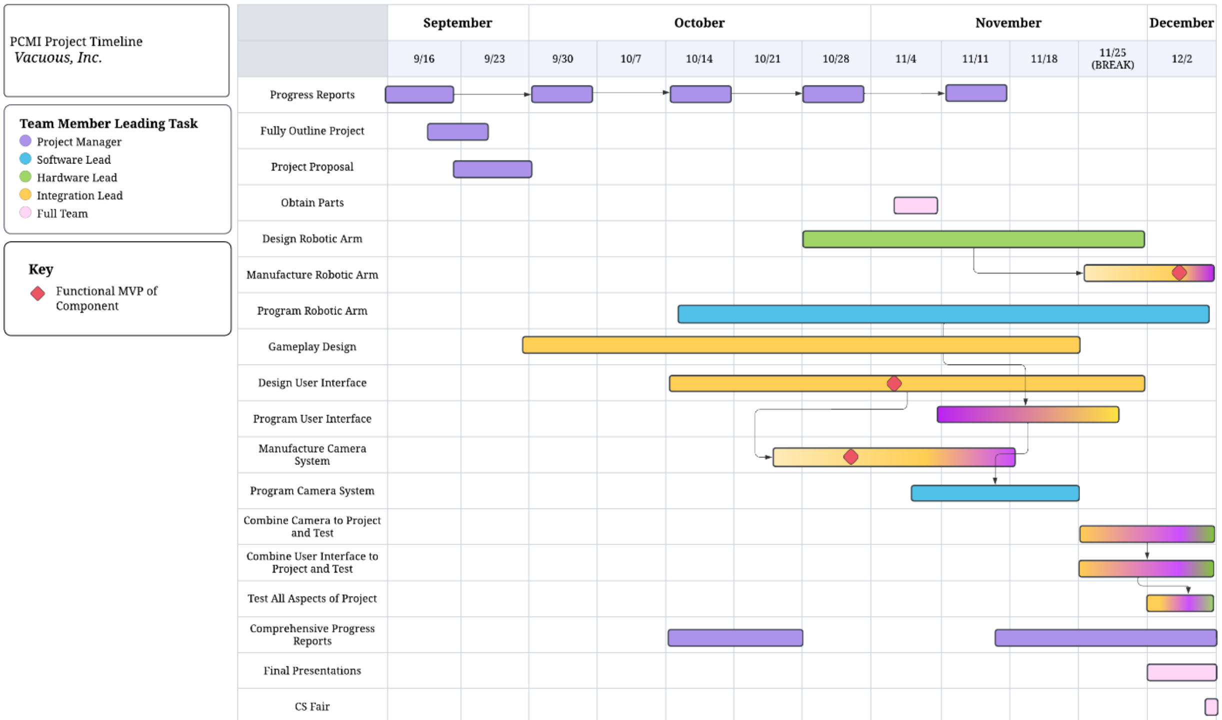
Project Plan

Estimated Gantt Chart

The figure below illustrates our project timeline from the beginning of the semester.



Actual Timeline



Functional Prototype

The Functional Prototype is most certainly the most difficult and extensive part of PCMI. For this reason, we have separated it into 3 sections: Robotic Arm, User Interface, and Camera System.

Robotic Arm

This component was the MVP of PCMI. It was also supposed to be the first section of the project, although it ended up being delayed until near the end. The arm itself was designed in SolidWorks by our Hardware Lead and 3d printed at the UVM Fablab. It went through two iterations while dealing with weight and torque issues. The Arm movement is powered by three 45 KG High Torque Servos, with a smaller AD002 Servo Powering the End Effector's rotation. All servos are powered by a communal power supply and controlled using RPi.GPIO's built-in PWM functions. The arm picks cards up using two 5V vacuum pumps powered from a separate power supply and controlled by a custom motor control circuit making use of a PN2222 transistor at its core. The suction is further controlled by a 5V solenoid valve that is again controlled by a PN2222 and powered by the same power as the pumps. For more details on circuits please view included circuit diagrams. Code integration allows the arm to be positioned to any point in radial space around the arm and to move cards efficiently between these points. For efficiency in presentation, specific points for players and dealers have been hardcoded.

User Interface

The User Interface has been developed using CSS and HTML. It consists of three pages, an intro page, a sign-in page, and a gameplay page. In the sign-in page, users can either create an account through their Google account, or play as a guest. The website it connected to a database which keeps all balance and wager information. In the gameplay page, users will be able to virtually see the cards they have been dealt, as well as take actions such as "hit," "stand," and "double down." They are also able to change their wager. Similarly, it also consists of an admin page from which the game is run. The User Interface can successfully hold up to 4 players, as well as a virtual dealer.

Camera

The camera system runs off its own, separate Pi. It makes use of a custom-trained machine-learning model to detect suit and rank of playing cards. This model was trained on 20,000 sample images over 25 epochs, taking several hours. The model is a trained YOLOv8 (You Only Look Once) model developed by Ultralytics. Libraries we use for the model include PiCamera2, matplotlib, numpy, and OpenCV2. The model can either run in standalone mode with a video preview, or in production mode it runs a flask app for the gameplay website to integrate with.

CS Fair

Although optional, Vacuous, Inc. has decided to participate in the 2024 UVM CS Fair on December 6th. We will use the information and code located in the Final Report to register and present at the Fair. This will allow us to fully demonstrate the work and ingenuity within PCMI.

Source Code

Source code is available on GitHub at https://github.com/Vacuous-Inc/PCMI.

*This is the most up-to-date code: there most likely have been changes, in preparation for the CS fair, that occurred after turning in the ZIP on Gradescope.

Citations:

All citations are included in the “credits” section of the GitHub, which can be found through a link in the README. In general, all code has been written by project members, except where noted in the credits file.

Final Report

Reflection

At its core, this project was created not only to give us a leg-up on future job interviews by having previous experience on computer science-based projects, but also to simulate a job environment. To go along with the physical and software components, the CS 2210 Final Project also included many traditional business aspects such as the proposal, progress report, and final report, which Vacuous Inc. had not previously encountered in similar assignments. Correspondingly, the lack of guidelines on the product itself allowed Vacuous Inc. to create something that each member was truly excited about, a characteristic that is very unique to this experience.

In many ways, this project was very helpful in preparing students for future opportunities. For example, all members of the team had to learn at least one knew skill/language in order to successfully accomplish this project. Similarly, as many tasks overlapped between team members, Vacuous Inc. was able to practice understanding and editing other people's code: a surprisingly difficult but important skill. Furthermore, as with the majority of group projects, Vacuous Inc. was faced with the challenges of scheduling and communicating between multiple people in a respectful yet effective manner.

Unfortunately, as with the majority of group projects, Vacuous Inc. faced many challenges and setbacks during the creation of this product.

Challenges

The biggest challenge of PCMI comes with the fact that the idea of it was made in the beginning of the semester. During this team, the team members did not know many important pieces on information, such as club schedules, workloads, and the level of burnout they would quickly face as the semester progressed. Filled with the naivety and energy most commonly seen at the beginning of the school year (and end of the summer), we set our expectations far too high.

Unfortunately, although this quickly became apparent, Vacuous Inc. was forced to submit a Project Proposal before any meaningful work on PCMI could occur. This cemented our project idea in the eyes of the Venture Capitalist, and, although some pivoting was able to occur, the team was unable to make any meaningful changes to our project.

The two biggest challenges came in the form of the Robotic Arm and the Camera. Although they were our two main objectives, and were known to be large undertakings, meaningful progress was not started until the last third of the semester. That is not to say that Vacuous Inc. was doing nothing during this time: the Project Manager and Integration Lead was able to make a large amount of headway on the User Interface as well as complete all necessary Progress Reports. Still, these delays left Vacuous Inc. scrambling, for lack of a better word, to complete the project before the due date, as can be seen through our Progress Reports. Furthermore, we had to get rid of multiple stretch components such as the Card Shuffler as we would not be able to manufacture them in time.

The unfortunate reality is that although this project was created to simulate a job environment, the members of Vacuous Inc. are not full-time employees. We are expected to each complete 32 hours of classwork (not including this project) outside of class time. Furthermore, each member has a separate job and multiple extracurricular activities. In the beginning of this year, Vacuous Inc. had no way to understand the full load of its responsibilities, and thus were unable to logically detail the requirements of the Final Project.

As the project progressed, the team then encountered many problems in relation to the creation of PCMI. To begin with, they found that the 3D-printed components of the Robotic Arm were unfortunately far too heavy for the servos. The Integration Lead then drilled all unnecessary material out, however the torque was still far too great. Vacuous Inc. ended up purchasing better-quality servos in order to solve this problem, and have completely redesigned the Arm multiple times. In our final design, the weight issue has been solved by attaching rubber bands in order to give upward tension. The second problem Vacuous Inc. encountered with the servos is a lack of available power, leading to them having issues with continual movement. The team attempted to solve this by attaching them to a separate 9-volt battery.

This is similar to what occurred with the motors. Due to a lack of power, they would continually stall out while trying to pick up cards. In order to solve this, Vacuous Inc. have the pumps running off of a separate pi.

Finally, the last large problem Vacuous Inc. encountered was with the Camera. After only a few moments, it would start to consistently halo. To go along with that, it also required very specific lighting in order to identify each card. The largest problem that Vacuous Inc. encountered, however, was when the SD card for the pi the Camera was running off of got corrupted. In order to solve this, we flashed the SD card.

Overall, Vacuous Inc.'s biggest challenge lied in amount of work done by the team. Although the Software Lead was responsible for programming the Robotic Arm, User Interface, and Camera, she was only able to complete the Camera, which was put together in the last weeks of the semester. This was the same with the Hardware Lead. Although they have put in a lot of hours, their work cumulated in two CAD models which were unable to actually work. Similarly, they did not begin to put in meaningful work until the very end of the semester, preventing in-depth integration testing. However, both of them declined to designate tasks or accept assistance from the Project Manager and Integration Lead. The Project Manager and Integration Lead attempted to make up for this deficit, but ultimately did not have the necessary time or manpower.

Takeaways

The first takeaway is that benchmarks are extremely important. Although Vacuous Inc. had a comprehensive Gantt Chart designed, it was treated more as a suggestion than actual deadlines. In future projects, Vacuous Inc. will most certainly try to adhere far more strictly to any timelines created. This project also taught the team the reality of the college experience, which is that you will most certainly have no time. Vacuous Inc. sees now that perhaps our professors were taking it easy freshmen year. This information will impact the complexity of any future projects Vacuous Inc. attempts during the remainder of our college experience.

On the other hand, Vacuous Inc. also learned many important technical skills. The Project Manager was able to increase her competency in writing business reports, learn HTML and CSS, and become familiar with object-oriented python. The Integration Lead was able to delve deeper into SQL, CAD, and circuit design. The Hardware Lead was able to gain proficiency in CAD as well, and became more familiar with resources such as the UVM Fabrication Lab. The Software Lead was able to learn and integrate machine learning into the project.

Overall, although there were many hardships and challenges interspersed throughout PCMI, at the end of the semester Vacuous Inc. was able to come out of it with important knowledge, skills, and outlooks.

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