Enhancing Early Childhood Education with Food Printing Technology to promote Multi-Sensory Learning

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1. Abstract

CAGR - Cumulative Annual Growth Rate

RoI - Return on Investment

BoM – Bill of Materials

ConOps - Concepts of Operations

OpsCon – Operational Concepts

AI – Artificial Intelligence

OS – Operating System

API -Application Programming Interface

LLM – Language Learning Model

ADB – Android Debug Bridge

ALSA - Advanced Linux Sound Architecture

CAD – Computer Aided Design

2. Introduction

This project aims to integrates food printing technology, commonly used in the food industry, into the early childhood education domain. The goal is to enhance learning capabilities by fostering engaging and interactive scenarios and to increase learning efficiency for young children. Our team developed a system to achieve this, leveraging innovative technologies such as speech-to-text and text-to-speech to create a unique educational tool that aims to utilize multi-sensory learning to create a better learning experience.

This report will highlight the team's workflow and thought process, from planning to realisation of the system. The document will also highlight the team's wins and struggles.

The results of the evaluation and future works of the system will also be highlighted in the report.

The documentation of relevant information at project closure and in addition, my personal contribution, reflection and proficiency gained or improved over the course of the project's duration.

3.Project Workflow

This section highlights the project's team and my personal contribution and workflow in detail in conceptualizing, developing, implementing and validating the system created, broken into various subsections.

3.1 Planning

The project has the following constraints imposed by the organization, Singapore Institute of Technology.

Firstly, the project was to be an improvement to an existing system, EVEBOT's PrintPen and use of this system is mandatory in our solution.

Secondly, was the lack of involvement of key stakeholders in the project. Primarily EVEBOT, the company that developed the PrintPen and the focus reference system of this project. This limits the amount of conceptual information such as the ConOps that is readily available. This means the project will have limited stakeholders involved in the project.

Next, the total allocated budget for the project was $500 dollars. This would greatly limit the scale and complexity of the project.

Lastly, the total schedule allocated to the project was 9 Weeks. This was a problem due to the project overlapping with other commitments of the project team and this will also affect material acquisition as lead times have to be considered for each component in the Bill of Materials (BoM).

Taking these factors into account, the team must first pre-plan several key models to understand the scope of the project.

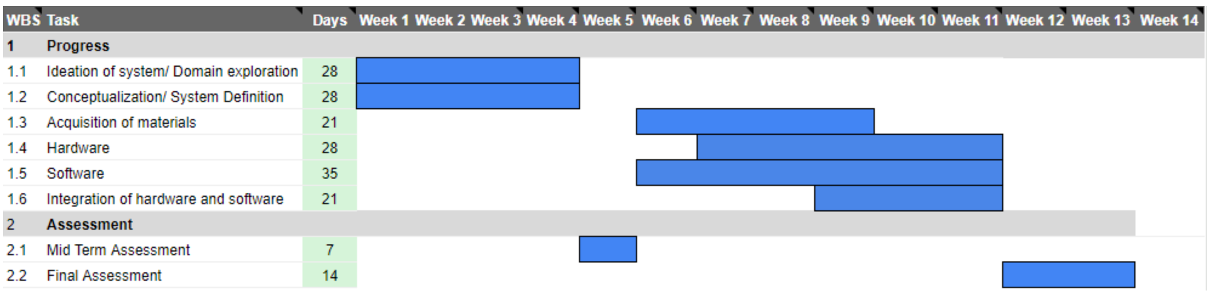

Figure 1: Gantt Chart to plan for Schedule Management

3.2 Conceptualization

The project team needs to understand the given domain, the food industry, and gather insights into the current standard, practices and outlook the food printing technology has on its own domain.

Food printing technology is still relatively new, within the food industry, mainly used as a form of novelty to improve visual appearance of food such as giving structure and/or unique shapes to food items.

Another use case scenario would be to allow for the reduction of food waste. For example, in vegetables, certain sections of the plant such as the stalk in celery can be grinded into paste and be used in food printing allowing for more sustainable practices to be formed in the food industry.

With this information on the food domain, the team can apply this technology to an application that may benefit by implementing food printing technology, within or outside the food industry.

The first iteration, the team tried to tackle sanitation. The team deemed that currently, within the food industry domain. one of the biggest gripes with the food printing technology which affected its adoption rate was the concern of contamination or food safety.

The stakeholders feared that there was the risk of making the consumers sick if proper protocols were not enforced or given as a package with the technology. The team explored and realized that the current functionalities of the technology did not tackle this need and the team deemed it possible to use this as our first focus for the system.

However, upon further discussion with the lead stakeholder within the organization, it was deemed unsatisfactory.

Thus, the team had the reiterate and find a new target domain.

The second round, the team decided to tackle on the Disability domain and believe that it was a worthy cause to justify making the system towards. The team explored the domain and concluded that there was more than one possible group of people that can benefit from having the food printing technology incorporated into their sphere of influence.

The team found evidence to show that people with disabilities tend to avoid eating out, due to their conditions but wishes to eat out and enjoy experiences that normal abled bodied individuals can do. The team are also able to find a key statistic called “The Purple Pound” where it highlights the spending power available of the disabled.

The team has also found that café owners were not utilizing these marginalized groups of individuals to keep their clientele numbers growing and depending on regulars to keep their establishment afloat. With these semantic links, the team chose this as our new focus for our system.

However, upon presentation to stakeholders of the project, it was once again rejected due to the ideation of the product being too difficult due to the complexity of the proposed solution.

The team decided to highlight another possible solution for another group within the same domain to the stakeholders but were told to rethink of another domain to tackle as it was deemed too niche of an audience and would not give a good Return of Investment (RoI) and that the market size is too small if it was to be rolled out into a real product.

At this point in time, the team only had 7 weeks to complete the project and was in dire need of a starting point. The team explored and came up with education as the domain of education has several key problems that can be tackled with food printing technology. It has a sizable market cap with an increasing CAGR (Cumulative Annual Growth Rate) on products. This would give the needed possible RoI potential on the possible system the team would be creating to tackle the problem or opportunity found.

Upon extensive research, the team found an opportunity where children can use food printing technology to promote efficient learning during mealtimes.

The team decided this was a topic of discussion and decided to pursue this as our finalized domain of interest.

After getting the target domain, we need to understand the benefits of integrating the food printing technology to this domain.

The team gathered that by implementing this technology, it would optimize the schedules in school, providing another avenue where learning can be implemented, at mealtimes. Secondly, another prevalent issue in the field of early childhood education would be the lack of user engagement. The team believe that food printing technology will allow for a new experience for the children.

Therefore, there is an opportunity present.

1. Promoting better user engagement in children in childcare centres to better support child development through interactive learning.

The team now must understand what the food printer is currently capable of functionally in order to create an innovative solution that tackles the opportunity.

The functionalities are listed as the following after analyzing current products like the EVEBOT pen for reference.

Evebot's PrintPen	**Ripple Maker**	**Functionality**
Can print edible ink	Can print edible ink	Print edible ink
User inputs either text or visuals through application called PrintPen	User inputs either text or visuals through application called WebApp	Receive customizable user inputs from application
Connects to application called PrintPen on phone	Able to connect to phone through WebApp	Connect to phone through an application
Prints on different types of food	Prints on different types of food	Prints on various types of surfaces
Desired Functionality:		Utilize multi-sensory features

Figure 2: List of Functionalities

The desired functionality is derived from examining existing systems and products from rival organizations in the same domain or from other domains that tackle the opportunity statement.

Examining the similarities between them, the team was able to single out the common factors between them. The functionality that ties them all together would be the apparent use of features that promote multi-sensory instructions or interactions.

The team explored multi-sensory learning and its positive effect on learning.

Multi-sensory learning will help children cope with standard techniques such as memorization. Furthermore, the use of other senses will help children in memory retention as certain words can be associated with related senses upon experience. That is one of many benefits that can impact the child's development.

Therefore, this would be the functionality that would be plugged into our system and be used as our starting baseline of what the system is expected to do.

Finally, with this, we can analyze the functionalities and come up with system elements that tackle each of the functionalities listed above in Figure 2.

The information gathered during this phase will be documented and can be used to inform and update the existing ConOps of the organization, EVEBOT, if they wish to increase their user base.

The team also created a Concept Model and a possible Use Case Scenario to highlight some high-level concepts and ideas into visual representation.

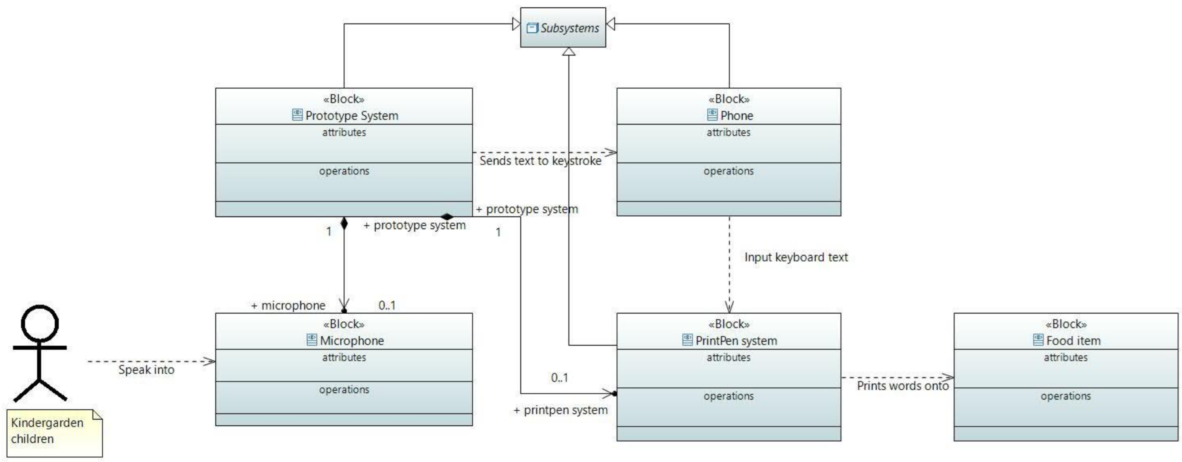

Figure 3: Proposed System Concept Model

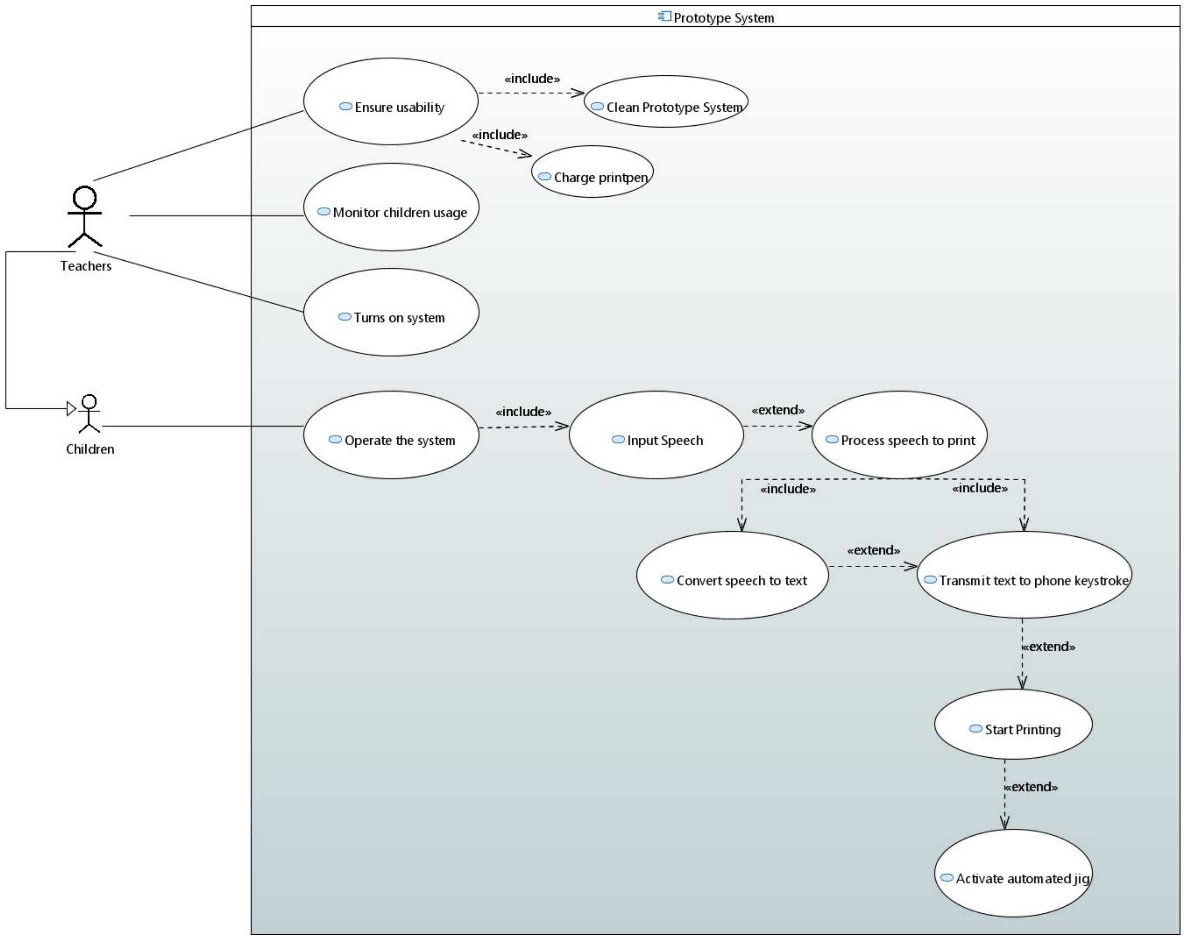

Figure 4: Use Case Scenario of Proposed System

3.3 System Design

The team needed a system that tackles this issue and came up with features that aim to target the senses of a human. The printer pen will provide visual stimulus while the auditory aspect can be solved with a speaker which can help facilitate learning by spelling out words letter-by-letter to help children with letter recognition.

As for the other senses, the team concluded that it can be indirectly stimulated due to the food the printer prints out. The smell, taste and tactile stimulation can be achieved this way.

By addressing multiple senses, the system aims to provide a comprehensive learning experience that can cater to different learning styles. The integration of these features ensures that children can engage with the learning material in a holistic manner, potentially improving retention and enjoyment.

The team created the high-level Physical Architecture to facilitate understanding of the system through a visual representation.

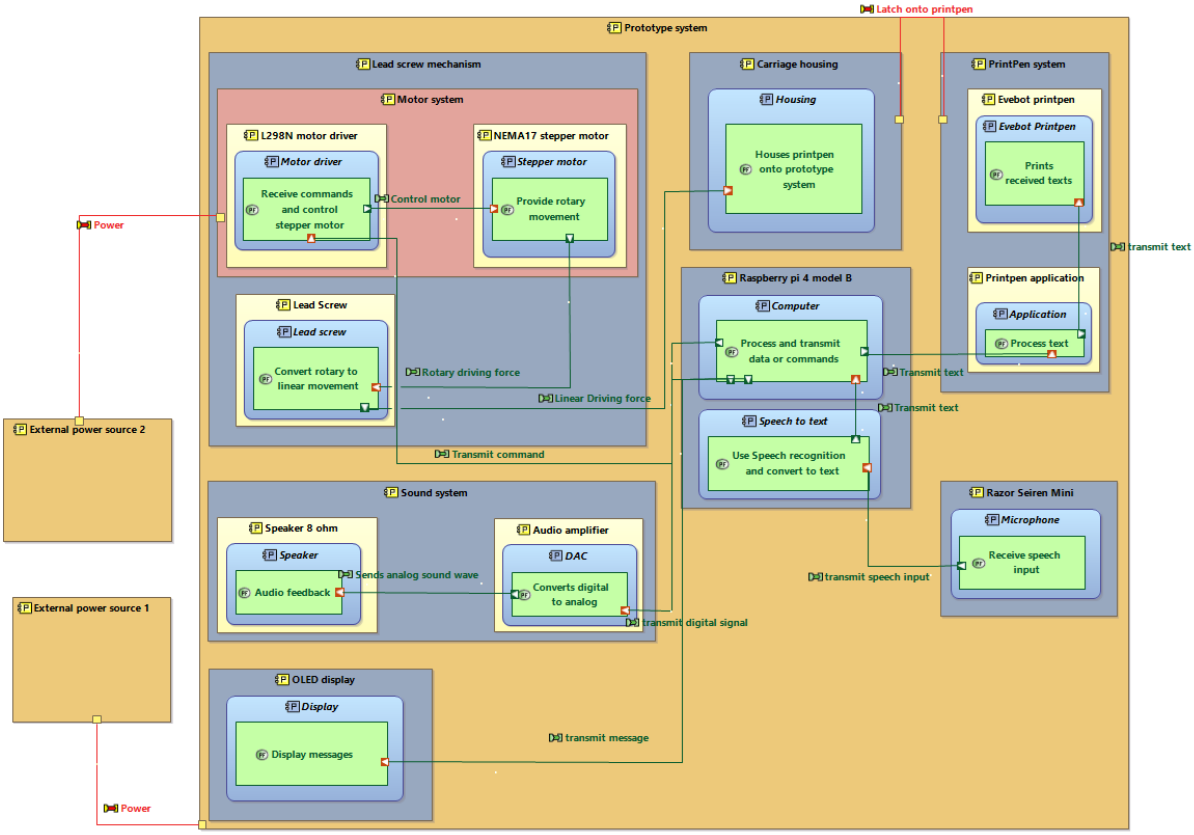

Figure 5: Physical Architecture of Proposed System

3.4 Implementation

This section highlights the thought process and detailed explanation on certain codes and processes which was declared in the System Design section (Section 3.3).

For the hardware and physical aspects of the system, fabrication techniques such as additive manufacturing (3D printing) and laser cutting were employed to create the rig needed to house the components and to provide structure for the automation. Workshop skills like the use of the bandsaw were used to cut the aluminum extrusion.

The second hardware component was the traversal system. Due to cost and time, the team decided to use a lead screw with motor to drive movement of a carriage. The motor used was the NEMA17 Stepper Motor which was compatible with the Raspberry Pi.

In addition, to facilitate communication to the Raspberry Pi 4, a motor driver was needed the selection of the L298N Motor Driver was due to the range of voltages it can take in as and output matches with the specifications of the Raspberry Pi and the NEMA17 motors.

Due to the lack of time for this project, the team decided for the prototype, the main axis of motion to demonstrate a level of automation would be to print out the word onto an object would be the manipulation of the x-axis.

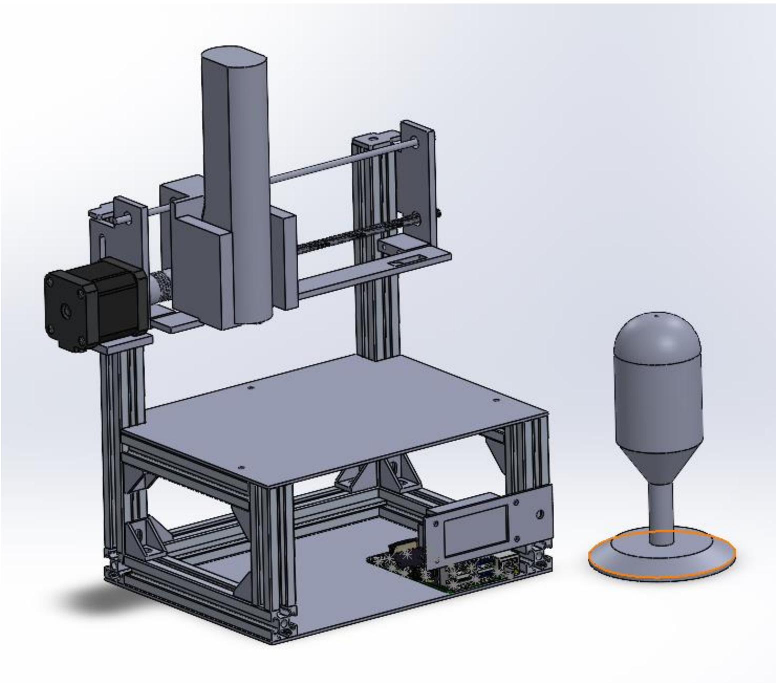

Figure 6: SOLIDWORKS Assembly of the System

For the software aspect, several languages and packages were used for various purposes. I will breakdown the aspects into portions and list down the implementation and its purpose.

Firstly, we needed a logic board to handle the computation needed and after extensive research and past experiences, the only viable contender was the Raspberry Pi. Furthermore, the team can source out the part from our organization thus reducing the cost needed for the overall project.

The Raspberry Pi is a microprocessor and can handle more complex computational logic than a microcontroller such as an Arduino. Secondly, another reason for the selection was the team needed the Operating System (OS) as programs were needed to download to control the mobile phone to access the food printer and currently, the API (Application Programming Interface) access was not given to us and contact with the parent company of the food printer was not possible after multiple attempts of contact. The team needed to create a workaround or a bypass to achieve one key functionality, the ability to communicate with the current application of the food printer.

The reason for the selection of a microprocessor was due to my research as I found an application called Android Debug Bridge (ADB) that works like other scripting services such as Hotkeys however, the application works for Android development and looking at this, I realized that we would be able to make use of this to achieve our desired outcome.

The installation was done using Linux, and the team was able to connect the phone to the application by recording keystrokes and using the phone as a medium to connect the food printer to the system, as this will be a prototype to showcase the functionality as a proof of concept, this is acceptable, and the final product will not have the phone to act as the middleman.

This would not be the only issue or roadblock to integrating the technology into the system.

Secondly, the technologies the team wishes to employ would be speech-to-text, text-to-speech and automation to achieve the desired benefit of stimulating their senses to achieve multi-sensory learning.

However, as mentioned earlier, the team ran into more roadblocks at every stage of implementation. The team needed to first know how the Language Learning Model (LLM) works for the speech-to-text aspect of the system. The team decided to use the open-source library provided by Google called Speech Recognition. This will allow the team to take advantage of the trained model instead of training the model from scratch, which will exponentially increase the difficulty and resources needed for project completion.

The implementation took considerable amount of time due to technical issues, as an attribute could not be found within the library and was only solved when we rollbacked the version used of the LLM. The issue was most likely due to the update, the developers found that attribute to be deprecated and removed it in future versions resulting in our code not being able to work. However, with the fix, the team can establish connection to the LLM and is able to achieve speech-to-text capability. The code for the speech essentially listens from an external output set by the Advanced Linux Sound Architecture (ALSA) configuration file for a specific sound card position upon running the script from the terminal. In the Raspberry Pi 4, there are 4 USB ports and 1 3.5mm Audio Jack which can be used to connect to the external microphone. A hardware issue the team encountered was that certain external microphones were unable to be detected by the Raspberry Pi, even with the addition of an external adapter for the USB port. The team attributed this to the hardware compatibility of Raspberry Pi's inbuilt sound card with the microphone's configuration.

The team now must first combine both of this subsystem together to achieve the initial data flow from the user using speech up to the data transfer to the phone. The code needed for this was considerably more due to unfamiliarity with ADB and Linux. The team decided to code it by storing the speech output from the user into a text file so that it can be altered, read and accessed easily across differing languages and platforms.

Using the text output, it simplifies the other functionalities implementation. The code for text-to-speech for the audio feedback will break down the word into singular characters, which is done by accessing the speech output text file and processing the characters in the string in a loop. It would then play the corresponding character audio which was added to the Raspberry Pi. The components used would be the I2S MAX 98357 which is a DAC converter and would help to facilitate the connection between the Raspberry Pi to a generic speaker.

With this, both the speech-to-text and text-to-speech aspects have been implemented and the automation works. However, all these subsystems and features work in a bubble, isolated and need to be integrated together to get the desired system behavior.

3.5 Testing (Verification and Validation)

The team conducted our integration tests to be as simple as possible, focusing on core behaviors instead based on the System Design and its expected output based on core concepts created at project's inception such as shown in Figure 4 which talks about what the system will do upon user interaction.

The team conducted the tests and deemed the results were satisfactory.

Since this system aims to prove that the solution is an upgrade or improvement of the EVEBOT PrintPen system, we need to compare and see if the functionalities identified at the start of the project still holds true, otherwise it would not constitute as an upgrade. Furthermore, with the addition of the desired functionality, proving this is a success would solidify that the system has more functionalities than its predecessor.

For Validation, since this serves as a proposal to the EVEBOT organization on the opportunity to expand into another domain, this report and system will serve as a exploration thesis and prototype that can break into this market. Therefore, there isn't a clear validation plan unless picked up by the organization to work on as a possible project, with clearly defined stakeholder needs and subsequently, a defined validation plan.

3.6 Evaluation and Future Works

The evaluation of the system was straightforward, and the expected output was shown to the stakeholders. However, there were issues with consistency due to several factors.

The stakeholder highlighted that the automation was not smooth and was bouncing.

However, overall, nothing of concern was highlighted and the team analyzed the system and created a list of all the needed modifications and fixes the system needs to do to be a full-fledged system or to be done for the next iteration of the system.

Future Works of the system includes an Auto Calibration System, this will eliminate the amount of manual labor needed to set up the system. Additionally, Smart Technologies can be employed such as sensors and vision to detect the object to handle certain functions such as detection as the current implementation is not ideal in a scaled up, finished product.

Another novel addition is the ability to generate art from speech. Currently, the product is only able to generate text based on speech, but the team has explored integrating the use of AI (Artificial Intelligence) to generate art using Stable Diffusion as the model and incorporating this feature into the product. However, due to the constraint on time, the team was not able to port this functionality into the prototype but is hopeful to experiment and add this in a future update to the final system.

3.7 Documentation

At project closure, the project's data has been collated and documented into varying databases. The code for the project has been documented and stored onto GitHub and the parts, assembly and other Computer Aided Design (CAD) files have been packaged and stored onto Google Drive.

These files and repository can be used for archival or future purposes if any organization or entity wishes to pursue this topic.

3.8 Personal Contributions

My role, as the Project Leader, involved overseeing the entire project from conception to delivery, utilizing systems engineering and project management principles.

I was leading the project and coming up with the flow of the project and facilitating understanding of key concepts to my group members. I was also acting as mediator for issues that crop up within the team.

In terms of the project realization, I was responsible for setting up the Raspberry Pi and creating the foundation for which our system would rest on. I also added the connections to the I2S MAX 98357 driver to the speaker and its related verification tests.

I was also in charge of making all the Computer Aided Designs and the overall look of the system. All the parts were created with the materials, methods of fabrication available to us, the time needed to make them and the core functionalities the system needed to exhibit considered.

Afterwards, I was also responsible into creating the physical structure of the system. I used manufacturing methods using simple workshop tools to complex machinery like the laser cutter.

Therefore, I was involved in the project, for some software aspects to hardware aspects, handling operations of the team in the background.

4. Reflection

This project serves as a testament to my current strengths and weaknesses.

Managing a project with many constraints and evolving constants is a tiring endeavor that requires constant focus and dedication. The human aspect must not be taken lightly either, a system or product can only be borne from the minds of humans; each with differing levels of commitment, ability and emotional wavelengths and as project leader, it was a challenge to mitigate discord and to foster an encouraging environment for the sake of the project, for the stakeholders involved.

Secondly, there is a fine balance between the inputs of the stakeholders and the product's feasibility and the team's capability and demands.

The more stakeholder input or needs that is taken into the project's scope, the possibility of the project becoming unfeasible due to constraints become more apparent. Therefore, the team must learn to elicit needs and pick out a set of needs to work with that are deemed necessary to create a system that will satisfy the success criteria of the stakeholder and solves the problem adequately.

5. Proficiency

As mentioned in Section 3.8, this section will highlight the proficiencies and skills gained or improved over the course of the project.

The hard skills that are improved would be Computer Aided Design and Fabrication. Coming from a mechanical background, having more experience helps to make these skillsets stronger. A new skill that I learned would be the use of new coding practices and applications such as ADB which was new to me.

As for soft skills, application of systems engineering concepts and project management principles were helpful to build a strong foundation for the future.

Lastly, as team leader, it helped me realize that human resources are also an important aspect in your system. This ranges from your group members to stakeholders involved. These factors will greatly impact the progress of the project and its overall success.

6. Conclusion

In summary, Like the project, where the team is creating an evolutionary improvement for the given system, this project will serve as my personal catalyst for my growth. This portfolio report showcases the project workflow that highlight my skills, creativity, and dedication to excellence. It also demonstrates my ability to tackle complex challenges, explore new technologies, and deliver innovative solutions. Through these endeavours, I have honed my technical expertise, problem-solving capabilities, and collaborative spirit.

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