

UCF Senior Design

Autonomous Recyclable Sorter



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Initial Project Document and Group Identification
Divide and Conquer

Group 9

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Chapter 1 – Project Narrative

It's no secret that the atmosphere is more vulnerable now than it ever has been. With an increasing amount of internal combustion vehicles on the road and waste products produced by humans at an all time high, it's important to protect the environment in as many ways as possible. According to the Environmental Protection Agency (EPA), roughly 75% of America's waste is recyclable; however, they estimate that only about 30% of that waste is actually recycled. As a result, the EPA estimates that at least 60% of waste currently found in landfills across the United States can be recycled. The U.S. recycling rate is around 32%. If we can devise a method to increase that rate to 75%, experts say the effect will be equivalent to removing 50 million internal combustion vehicles from the roadways.

This is where we (group 9) step in to combat the issue as much as possible and increase the U.S. recycling rate as much as possible. The most important question to ask is, why aren't people recycling given its importance? The truth is, humans are lazy and do not care about the environment enough to take the extra step to recycle. Additionally, traditional waste management facilities rely heavily on manual sorting processes to separate recyclable items from waste. The problem with this approach is that it leads to significant inefficiencies, human error and increased operational costs. For example, the employee at the facility can simply miss a plastic bottle that could have been recycled. Multiply this by a few times per day per employee and you can see how this quickly becomes a significant contributor to the issue at hand. Furthermore, the costs required when utilizing manual labor means there's a limited amount of employees at any given time which leads to a more frequently missed item.

Our project, The Autonomous Recyclable Sorter is designed to directly combat the issues mentioned above. The idea is that it will be able to be installed in all public waste baskets and even scaled up to be implemented at sorting facilities to account for private waste baskets located inside homes and other private locations. Utilizing modern technology and innovations such as inductive and capacitive sensors, our sorter will be able to identify plastics, metals, glass, and paper products and separate them from waste. In a perfect world, this invention would allow all trash to be put into the same baskets and leave the sorting/recycling up to the machine to minimize errors and maximize recycling potential by eliminating the human variable. Some of the major objectives include, developing a robust and cost-effective recyclable sorting system, and making the system as effortless to use as possible. We strive to develop a scalable solution that can be implemented in various locations across the world and promote global efforts towards a greener and cleaner environment.

Chapter 2 - Project Description

2.1 – Specification

- The device will be powered by portable power sources such as solar (preferred) or batteries.
- The device will utilize image processing software to identify materials. - **DEMO**
- The device will accept 1 item at a time.
- The device will use a swing arm mechanism to change the course of the item and direct it towards waste or recyclable.
- The device will utilize a retractable door system that serves as a buffer for the items inserted.
- The device will be able to identify, and successfully direct it to the proper destination in under 10 seconds. - **DEMO**
- The final design will be able to store (2) 5 gallon bins. One for waste and the other for recyclables.
- The final product's dimensions will be equivalent or smaller than the typical 20-30 gallon examples found in public facilities such as college campuses (UCF).
- The device will be able to successfully sort out recyclable items with a success rate of at least 80%. - **DEMO**

2.2 – Project Constraints

Cost: Collectively as a group, we have decided to attempt to stay under \$500 total to design, manufacture and test our product. The major costs for this project will be the sensors, motors for our door and swing arm, and the materials used to create the housing.

Time: Considering the fact that we only have roughly 25 weeks to research, design, develop and manufacture a final product, time is something to be wary about. The good thing is, we knew about the time constraint during the brainstorming process which allowed us to choose realistic ideas given the allocated time frame.

Space & size: We do not want our product to occupy more space than the typical waste baskets you see around campus. Creating too large of a product will ruin it's practicality and potentially discourage possible clients.

2.3 – 3-Level Goals

- **Main Goal** - Create a machine that is able to identify and sort at least 2 different common recyclable materials.

- **Advanced Goal** - Create a mechanical system similar to a buffer that allows users to input at least 2 recyclable items at once.
- **Stretch Goal** - Developing a machine that's able to identify and sort the 3 common recyclable materials and also handle traditional waste.

2.4 – Prior Related Work

Pre-designed components are crucial to any final end product. These pre-designed components provide a level of support and a base foundation for our team project. Using these widely available and reliable systems will prevent the team from reinventing the wheel. It will give the team a base foundation and place to begin building an exceptional product.

OpenCV - is an open source tool kit and an api which provide high accuracy object recognition. OpenCV allows our system to have an 80% recycle filtration accuracy. Distributed under an open source Apache license, OpenCV is directly and fully integrated into our system for seamless deployment.

Linux - is an open source computer operating system designed to unleash the full potential of all OpenCV powerful tools. Working in direct and harmonious relationship with each other Linux and OpenCV will fade into the background as the system begins to identify and catch recyclable objects.

Raspberry Pi - provides a solid foundation and reliable host platform for both operating and image recognition suites. The Raspberry Pi provided the proper specifications to fully accelerate and bring superior image processing capabilities.

2.5 – Objectives

1	Develop software to successfully identify recyclable materials.
2	Create a mechanical system that can redirect materials into at least 2 different directions based on variable input.
3	Design a PCB with all necessary sensors, motors, and MCU controls working.
4	Construct an intuitive housing for our machine that conceals the components and appears to be an ordinary trash basket.
5	Develop prototype simulation using breadboard, MCU, and image processing software to confirm pin out and performance.

Figure 2.1 Table of Objectives

2.6 – Budget Estimates

Description	Quantity	Estimated Cost	Estimated Total
PCB	2	\$80	\$160
Camera	1	\$60	\$60
Servo	2	\$50	\$100
Actuator	1	\$30	\$30
Housing and Release Mechanism	1	\$40	\$40
Estimated Total	-	-	\$390

Figure 2.2 Budget Table

Each of the items listed in the table above are expected to be incorporated into our design. It is foreseen that an operating system of some sort will be required so we can incorporate image detection software. The software is likely going to be more robust than what is capable of being supported by a basic MCU as memory tends to be a limiting factor. With regards to the software, we are intending on using a more dynamic MCU that meets the demanding specifications expected for the software integration. In addition, to meet the significant PCB requirements the MCU must be surface mounted to the PCB. Considering the factors mentioned it is expected that our PCB design, including the MCU, will cost roughly \$80. In addition, we would like to allocate a budget for a secondary PCB as a contingency plan for any unforeseen circumstances such as a lemon product or an oversight in design. Hence the quantity for PCB is listed as two and the estimated cost total of \$160.

The design is intended to recognize a constrained set of items in real time using a camera. The camera chosen must have quality image capturing and transmission capabilities for our software to differentiate between the items in a timely manner. Considering the options for cameras, and the possibility that the design could require capturing images in a low-light setting, we expect to spend no more than \$60 on this component. The design is expected to sort between the sets of items which infers that a sorting mechanism must be integrated. In this process, it is likely that at most two servo motors could be used. The motor(s) must be durable and have consistent accuracy. A mid-level servo motor of at most \$50 is expected to fulfill the requirements for our sorting mechanism and final design. The ceiling total of the two motors is expected to be no more than \$100. In addition to the servo motors, we do foresee a possibility that an actuator may also be a component in the sorting mechanism. To account for this, \$30 is being included in our estimated budget. The last portion to consider is a housing to contain all of the components including and the different bins that the sets of items will be sorted into. Considering that the housing will be dependent on all

other components, we are unsure of what it will entail. That being said, a budget of \$40 is taken into account to design and build out the housing necessary.

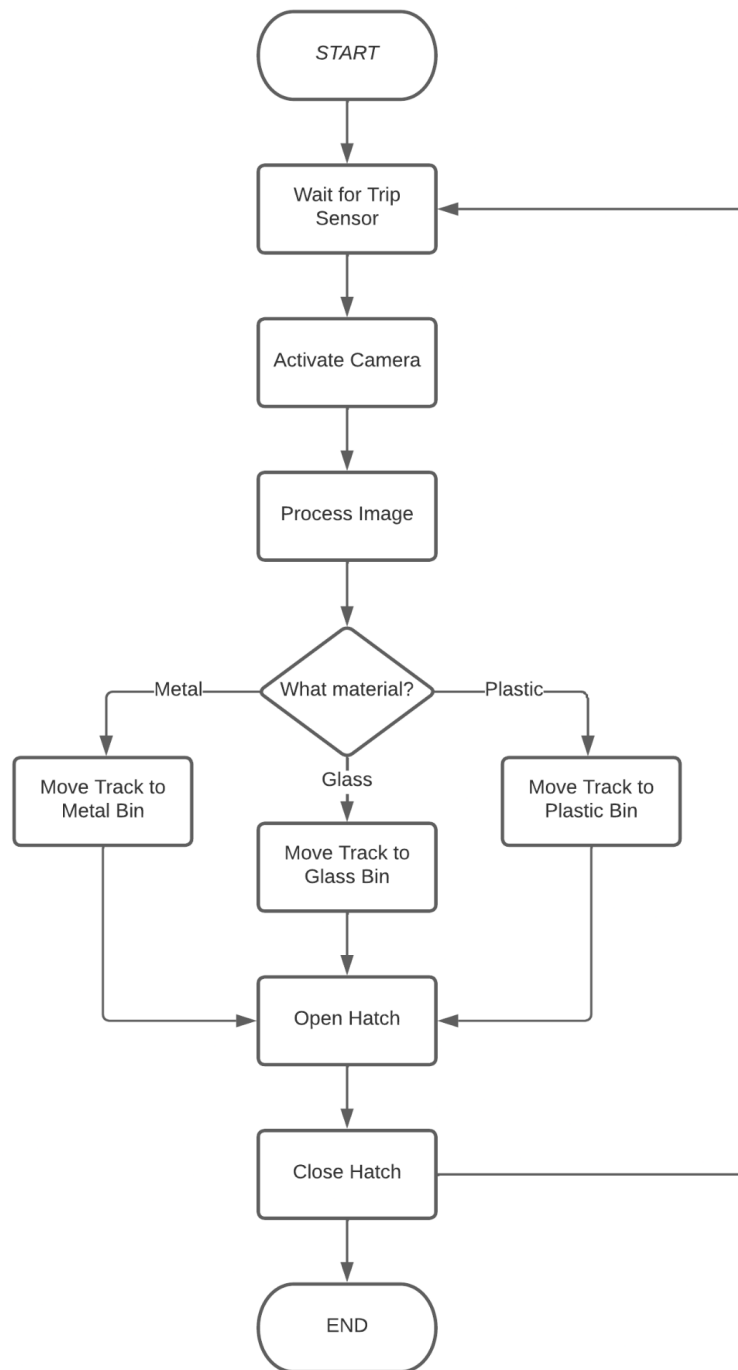
Overall, the total estimated cost of the entire design is \$390. Our team has agreed to put forth \$150 per member for a total of \$500 budgeted for this project. This allows for a \$110 buffer for any significant design changes or unexpected costs moving forward.

2.7 – Decision Matrix

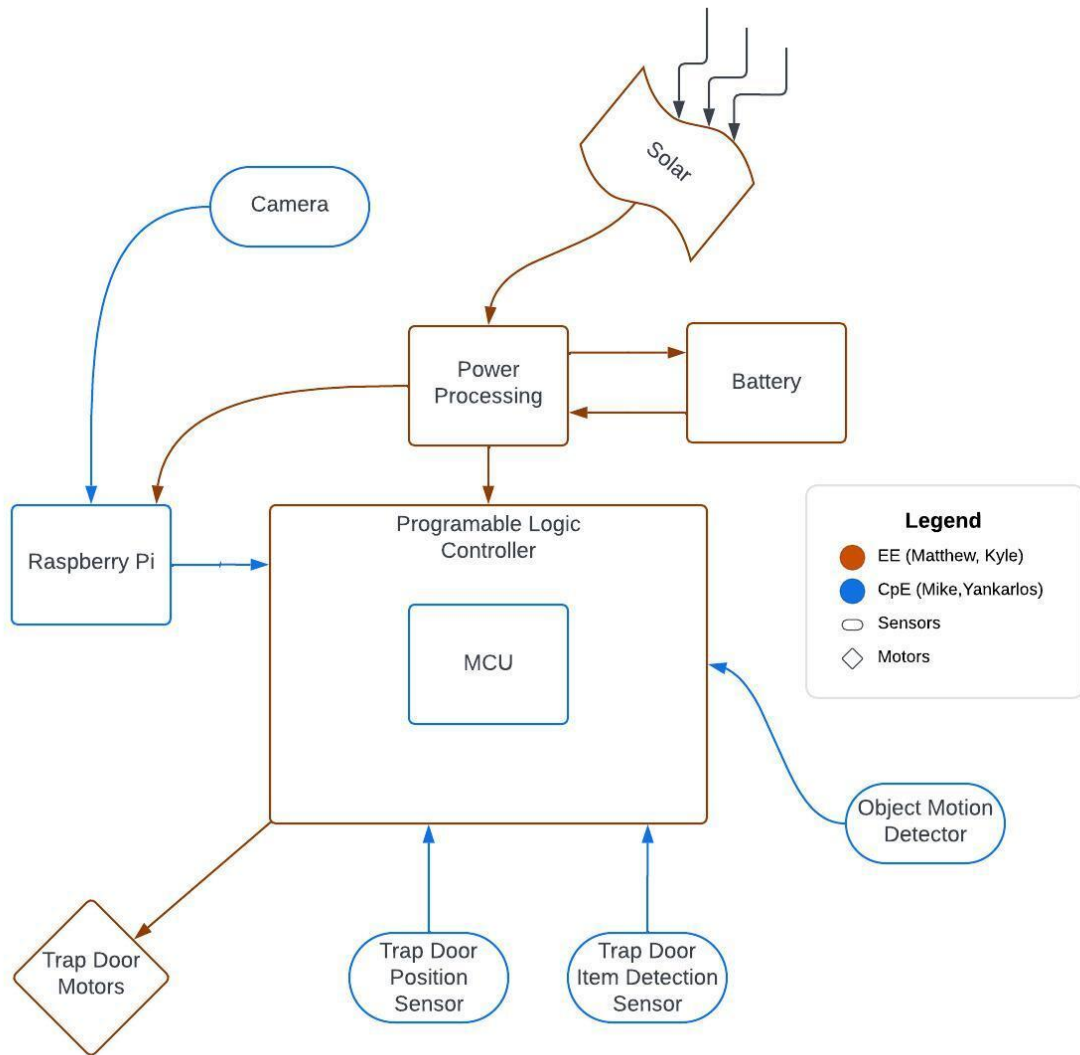
Correlation matrix	
++	Strong positive
+	Positive
-	Negative
--	Strong negative
	Not correlated

		Efficiency	Dimensions	Power Use	Install Time	Cost	Quality
		+	-	-	-	-	+
Cost	-	-	+	+++	+		--
Performance	+	++		-		-	++
Install Ease	+		++		++	++	
Maintenance	-	-	+		+	+	-
Portability	-	+	-		-	+	-
Target Specs		> 80%	20"x20"x40"	< 40 W	< 10 Mins	< 500\$	> 80%

2.8 – Software Diagram



2.9 – Hardware Diagram



Chapter 3 – Research

3.1.1 – Software

When it comes to image detection and processing, choosing the right software can significantly impact the effectiveness and efficiency of our product. Given the specifications and constraints created during the design process of this project, the program we decide to use must satisfy a few constraints to be considered a viable option for us. First, our hardware is going to be one of the following options: system on chip, Raspberry Pi, or MSP microcontroller. Regardless of the final decision, these all have a few things in common, limited flash memory. Some of the software options available require the use of an operating system while others don't. In this section, we will be going through the top software contenders for our application and evaluating their strengths and weaknesses as it relates to our project.

3.1.2 – OpenCV

One popular option that offers a wide range of capabilities is OpenCV. short for Open-Source Computer Vision Library, is a versatile and widely used open-source software library. It provides an extensive set of functions and algorithms for image and video analysis, making it a powerful tool for computer vision tasks. When considering the use of OpenCV for image detection and processing for our product, there are both positive and negative aspects to consider. On the positive side, OpenCV is a versatile and widely used software library with an extensive collection of functions and algorithms for computer vision tasks. It offers a comprehensive set of tools for image manipulation, filtering, feature extraction, and object detection, providing a solid foundation for our application. OpenCV's broad user community ensures ample resources, tutorials, and support, making it easier to learn and troubleshoot.

OpenCV is a library of programming functions catered towards computer vision for applications such as facial recognition in real time. Originally developed by Intel, the library is cross-platform and free to use. OpenCV contains upwards of 2500 algorithms solely for computer vision related tasks which in its complete form, occupies upwards of 4GB of memory. For a personal computer such as a laptop or even a desktop, this wouldn't be an issue. However, since we are going for an autonomous approach, we need self-sustainable and compact devices to form the product. We want to incorporate as much as possible onto our printed circuit board and aid in keeping the product as compact as possible. Having to use a laptop to run the software that's essentially the heart of our product would be counterproductive. It would require a user or a significantly larger enclosure to house a PC which is far from ideal.

On the positive side, OpenCV allows the user to “prune” the software and only download what is necessary and leave out the features that will not be interacted with. This is vital for applications like ours where space is limited. We can essentially create a “lite” version and tailor it to our specific needs. Using the pruning technique, some users have been to run very basic versions of OpenCV on as little as 500MB of RAM. For our project, however, we would need at least 2GB of RAM, either a 32-bit or 64-bit processor, and an operating system.

	“Pruned” Version	Full Version
Python Libraries	210 MB	564 MB
Python Libraries	4.3 MB	6.9 MB
OpenCV Libraries	10.2 MB	39.6 MB
OpenCV Headers	2.3 MB	8.2 MB
Third Party Libraries	2.3 MB	8.2 MB
Total	229.1 MB	626.9 MB

Figure 3.1.1. Space comparison between stripped version and full version of OpenCV
(Reproduced with permission from Riens Politiek from Q-engineering)

As shown in the table above, stripping down OpenCV can be extremely helpful in memory conservation. In the pruned example demonstrated above, we were able to reduce the space by roughly 65%. Exactly which features are left out or included will be different for each user so the information above was just to highlight how useful the technique is and should not be referenced as concrete information.

However, OpenCV's extensive functionality also comes with a drawback for our specific application. The library, being feature-rich, might have a larger memory footprint, which could be a concern given the limited flash memory on microcontrollers or minicomputers like the Raspberry Pi 4. Additionally, while OpenCV can be optimized for ARM-based platforms like the Raspberry Pi, it might still require careful selection of modules and optimization techniques to reduce its memory usage and tailor it to your specific needs. Therefore, while OpenCV offers powerful capabilities, it's essential to carefully manage its memory consumption and choose the necessary modules for optimal performance in your resource-constrained environment.

Furthermore, the need to have an operating system to run OpenCV is another downfall. To run an operating system, you need hardware that's capable of supporting the operating system. That greatly limits our options because it rules out microcontrollers as possible hardware solutions. There are two options,

a raspberry pi, or a personal computer (PC). Our intentions are to incorporate our processor onto our PCB and needing an operating system increases the complexity of the PCB design significantly. If we were able to use a micro-controller, we would be able to download the chip's footprint and integrate our hardware using a PCB design program such as Autodesk Eagle.

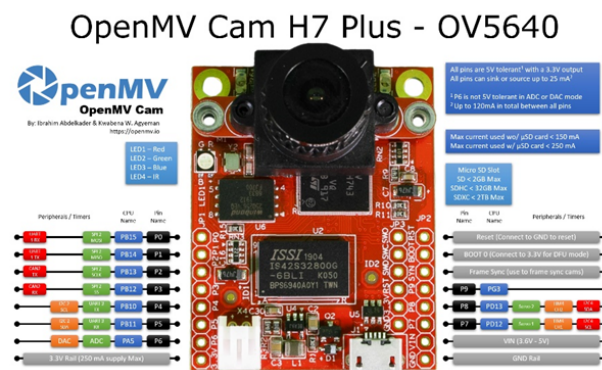
One way to work around this issue is to utilize the raspberry PI as a separate component from our PCB. We would design a PCB with a microcontroller chip that would control all the other hardware present in the project based on input received from the raspberry pi computer. We will connect the PCB to the computer using a serial communication protocol such as UART or I2C to allow for seamless communication. The raspberry pi series of computers are relatively compact and will work well within our space constraints. The issue with this is that we prefer to have a more inclusive design and limit the number of external components as much as possible. We would prefer to have the main processor on our PCB for a clean and sleek design and approach to the project. Having an external raspberry pi connected to our PCB makes the project feel poorly designed and rushed. Worst case scenario, we could fall back on OpenCV if the main approach doesn't work out.

3.1.3 – OpenMV

On the other hand, OpenMV is a specialized software designed specifically for microcontrollers with built-in cameras. It offers a simplified and lightweight approach to image processing, tailored for embedded systems. In recent years, the field of computer vision has witnessed remarkable advancements, allowing machines to perceive and interpret visual information with increasing accuracy and efficiency. OpenMV, a popular open-source machine vision platform, has emerged as a powerful tool that enables hobbyists, researchers, and professionals to take advantage of the potential of computer vision technology. OpenMV combines a compact hardware module with a comprehensive software library, filled with machine learning algorithms. It provides a user-friendly interface for developing vision-based applications such as object detection or facial recognition. Like any technology, however, OpenMV is not perfect and has its drawbacks and advantages as it relates to our autonomous sorter.

The way OpenCV works is by purchasing an OpenMV cam which is integrated into a microcontroller. Unlike the OpenCV route, this comes as a complete all in one package. You then download the OpenMV specific IDE which shows the camera image, histogram, and code development area. From here, you just write your code in python and upload it to the board like a traditional microcontroller such as Texas Instruments MSP series of boards. The OpenMV camera also supports I/O and serial communication protocols such as UART and I2C to allow for connection to other microcontrollers or computers. The OpenMV Cam H7 plus is the latest and greatest OpenMV camera so it's the one will be

referencing and the one we will use if we decide to proceed with this approach. The H7 plus features an Arm Cortex m7 processor running at 480MHZ with 32MB of SD RAM and 1 MB of SRAM. It also has 32MB of external flash and 2 MB of internal flash memory. All the I/O pins output 3.3 Volts and can tolerate up to 5 volts. On the board itself, there is a microSD slot that allows up to 2GB when using a SD card, 32GB when using SDHC card, or 2TB when using a SDXC card. Given the nature of the OpenMV camera and the way the system operates, we believe these specifications and performance numbers will be suitable for our application.



have done this multiple times throughout our educational career while installing various programs needed for our classes. However, it just adds another layer to the complexity of our project and simplicity is what we are after. If we can achieve the same result using the simpler path, that's what we would prefer to do.

Like the raspberry pi and OpenCV approach, using the H7 camera and microcontroller board makes it rather difficult to implement into a single PCB like we want. The good news is that since OpenMV doesn't require an operating system, the components needed to recreate this board on our own PCB will be significantly smaller and easier to complete. The problem is, OpenMV does not sell these components separately so obtaining a chip footprint and footprints of other components to implement into our design will be impossible. Not only that but if we did manage to get footprints, we wouldn't be able to buy the components to have them put on our board. This ultimately means that we would need to implement a similar work around to the one that was explained in the OpenCV section. If significant PCB design was not a requirement for this project, then we could simply use the H7 camera and microcontroller as our main processor to handle everything we need such as servo motors and actuators. However, we need to have a significant PCB design which means we would need to use a separate microcontroller to control our actuators and servos. The second microcontroller, which would most likely be an MSP board from Texas Instruments, would receive input from the H7 camera and perform operations based on that. For example, the camera will send out a signal when it detects green colored objects. The signal is then interpreted by our MSP board which performs the respective action for that signal. This seems like a bunch of unnecessary steps that complicate the system, which is the main downside to all of this. We would clearly prefer to integrate everything onto a single board but that's simply not an option.

As mentioned previously, the OpenCV approach required a similar workaround. However, since OpenMV is a self-contained system with no operating system, it allows us to keep our design as minimalistic as possible.

Lastly, another major benefit to choosing the OpenMV approach over the OpenCV approach is the power solution. The H7 camera and microcontroller features a port that allows us to utilize a 3.7 volt, 1500mAh lithium polymer rechargeable battery. The raspberry pi that would be used in conjunction with OpenCV has very limited options for power that would be appealing to our use. The ones that would work for our product are too big and would push us further away from our space constraint.

In conclusion, the OpenMV and H7 camera with built-in microcontroller seems to be the clear choice for us so far. Its focus on power consumption performance, ease of use, and compact design cater very well to our needs.

3.1.4 – Google Cloud Vision API

The Google Cloud vision API is an extremely powerful cloud-based service that offers a wide variety of computer vision features and abilities. It gives users the ability to integrate efficient computer vision algorithms such as image recognition and analysis into an assortment of applications relatively easily.

The Cloud Vision API by Google works by accepting images as an input and conducting a thorough analysis on the images. The analysis process can recognize objects and extract information from those objects as well. For example, if we sent the API an image of a person, the analysis would be able to detect that image is that of a person and examine facial features to determine the mood of the person. It looks for key features such as a smile or frown to help make the determination. Additionally, the API features an optical character recognition algorithm that allows the API to extract text from images in various languages.

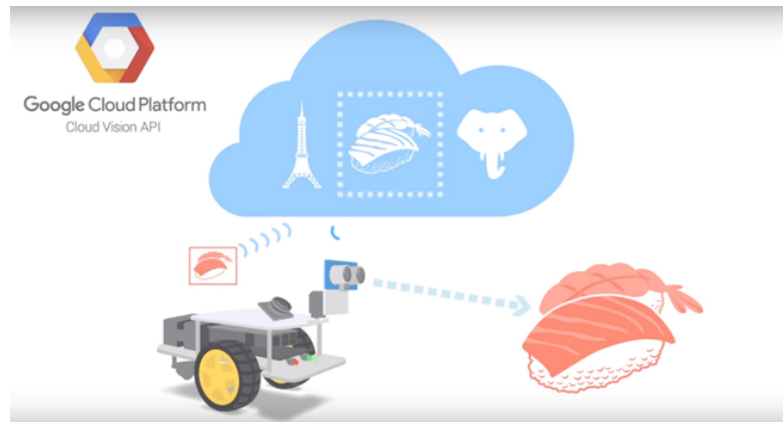


Figure 3.1.3. Google Opens its Cloud Vision API to all developers. (PENDING PERMISSION)

To use the API the user needs to first set up an account with google and receive an API endpoint key that grants them access and permission to use the software. The API endpoint receives the images through HTTP requests like many popular platforms. After the image is processed by the API, the response is returned through a JSON response with the detailed analysis. One-way developers can incorporate the API seamlessly is using client libraries that are provided by Google and support a variety of programming languages. Some important information to note is that the API clearly requires a stable internet connection. Without internet connection, our images will not be able to be transmitted to the API to be analyzed. Even having a weak or slow internet connection puts our project at risk of underperforming. Our goal is to be able to design a product that can work in various locations including parks, offices, schools, etc. While many of those places will likely have a stable internet connection, places like parks and other remote locations become variables. We

wish not to be confined to locations with stable internet, so this is a major aspect to take into consideration when deciding a program to run.

Furthermore, unlike the other software discussed previously, the Google Cloud Vision API has a cost associated with it. The first 1,000 photos sent to the API will be analyzed free of charge but after the first 1,000 photos, there's a charge of anywhere from \$1.50 up to \$3.50 per image. It's important to note that these numbers are reset monthly. Meaning, every month we get 1,000 free API hits and the numbers do not stack. During the initial prototyping and testing phases of our project, it's highly unlikely that we will exceed the free 1,000 photos granted by Google. However, the goal is to deploy our units nationwide and some day globally. With thousands of our products out in the world, we will quickly surpass the 1,000 free photos and start incurring charges. These charges will have to either be passed down to the customer or paid by the manufacturer of the product which would be us. Either way, this drastically increases the cost of the product and discourages potential customers from purchasing. This API is an extremely capable technology which has a ton of features that we simply won't be able to take advantage of due to the nature of our project. If we were to go down this route and use the Cloud Vision API, it would be a poor use of funds because we will be paying for advanced features that we can't use. We would be much better off using a simpler computer vision library like OpenCV because it's free and contains all the features we need. It's not as advanced as Cloud Vision API but it has everything we need. Lastly, the previous software we discussed is all inclusive and is downloaded libraries. This means that once we set it up and train the algorithms to successfully identify and sort the recyclables, we will no longer need the internet to operate the machine. Following that, we must discuss how we would implement this technology into our machine. Cloud Vision being an API means that we need an operating system with a stable internet connection to communicate and connect with the API. Similar to the conflict we discussed with the raspberry pi and OpenCV approach, this API requires an operating system. One of the requirements is to conduct our own significant PCB design. Without this requirement, we could easily take a single board computer (SBC) and integrate the Google Cloud Vision API. The problem is the PCB design. We would ultimately have to use a single-board computer to run our image detection software. On top of that, we would need another microcontroller to receive input from our single board computer and manipulate the servo motors and actuators based on that input. This workaround allows us to still design a PCB and meet that significant design requirement while utilizing an operating system to run Google Cloud Vision. However, having 2 boards makes the machine less compact and introduces more components to fail. The complexity of the machine increases with no real benefits compared to other options. Powering the boards also becomes another obstacle. The OpenMV board allows us to power the system with a rechargeable battery. Most of the single board computers we have seen require a wired connection to another personal computer or a bulky battery pack.

Overall, the approach required when using the Google Cloud Vision API is closely related to that of the OpenCV and single board computer approach. The downside to the Google Cloud Vision software is that eventually, the program will start costing money to use. While it does hold impressive features, to reach our goals and aspirations, they are not required. Going with Google's solution to computer vision will incur additional costs that simply cannot be justified. If our team was to go down the route of using a single board computer such as the raspberry pi to incorporate an operating system, we would rather use the OpenCV libraries over the Google API. If our project was more advanced, such as implementing an emotion detecting robot, then I could justify the additional costs because the advanced features present in the Google Cloud Vision API would be extremely beneficial. However, when simply determining whether an item is made of glass, metal, or plastic, those features are simply useless for our application.

3.1.5 – Generic Overview of Other Options

The computer vision industry is quite vast and there are a ton of options that suit pretty much an application you could imagine. Above we discussed the most suiting software and programs for our autonomous waste sorter project. Our waste sorter project is planned to be like an embedded system. No, external computers or user input ideally will be needed. The other computer vision software options that we researched usually required high-end system specifications that were far from realistic for our project. Utilizing these alternative software options would most certainly require an external computer such as a high-end laptop to run the software, which defeats the purpose of our product. Some of popular alternatives referenced in the previous paragraph include but are not limited to, Syte, Dataloop, SuperAnnotate, and Azure Content Moderator. While these programs are certainly impressive, it would be difficult to implement into our current design idea and constraints.

3.1.6 – Concluding Statements

All in all, there are computer vision programs available for all sorts of applications and projects. The three options best suited for our project is OpenCV, OpenMV, and google vision API. The issue with OpenCV was the need to have an operating system such as Linux to use the libraries and algorithms developed by the OpenCV team. The need for an operating system meant that we wouldn't be able to simply use a microcontroller chip such as the MSP series from Texas Instruments. We would have to resort to using a single board computer (SBC) such as a raspberry pi. This would be perfectly fine for our project because we could utilize GPIO pins to control our actuators and servo motors. The issue with this approach is the fact that it doesn't require any PCB design and fabrication. Designing and fabricating a printed circuit board that contains extensive design and planning is a core requirement in our project. Utilizing the raspberry pi and OpenCV method limits us from reaching this goal.

The only way to use OpenCV on our project is to have a raspberry pi run the object identification program and have a microcontroller chip receive input from the raspberry pi and control the actuators and servo motors. It's a workaround that adds complexity for no apparent reason other than to achieve the PCB design requirement. This introduces more steps which creates more areas for bugs and issues to present themselves.

Next, we have the google vision API. This software falls victim to the same cons as OpenCV for this application. It will require some sort of operating system to initiate the connection between the system and the API endpoint. This ultimately means a similar workaround approach is needed to utilize the Google Vision API in this project. Additionally, the Google Vision API requires a stable internet connection. This introduces another limiting factor and constrains us to environments with the internet which excludes most parks and outdoor settings. OpenCV does require an operating system but since it's a collection of libraries and algorithms only, once the initial download and setup is complete, internet access is no longer a requirement to use the object detection features. Lastly, the Google Vision API eventually will have a cost associated with it. They grant us about 1,000 scans for free but after that, it's about \$1.50 per scan. So, if we were to decide to implement a single board computer to utilize an operating system, we would most likely choose to use OpenCV because of its no-cost to use ideology, and the fact that internet connection is not required after initial setup.

That brings us to our final consideration, OpenMV. OpenMV seems to be the most suitable object detection solution for our project. OpenMV is optimized for use in embedded systems projects like ours. It's an open source solution which allows us to modify the board to add our servo motor and actuator connections. This allows us to meet our PCB design requirements and develop a single board that will control the entire system. Also, it doesn't require an internet connection to run the object detection or setup the device (Except for downloading the IDE). OpenMV also has a low entry cost considering the hardware and software capabilities. The newest OpenMV model, the H7, starts at about \$60. The only downside we found regarding OpenMV was the language used to program the device. C and C++ are traditional embedded system languages which is what I'm most familiar with. OpenMV however, uses python as its native language. I personally have no experience with python, but it's often regarded as one of the easiest languages to use and learn. Learning a new language at this point is not that difficult since the core concept between programming languages remains the same. The only difference is usually syntax.

 - Currently selected option for project.

	Cost	Language	OS Needed?	Open Source?	Implementation Complexity
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OpenCV + Raspberry Pi 4	\$55	C++	Yes	Yes	Medium
OpenMV	\$100	Python	No	Yes	Low
Google Cloud Vision API + Raspberry Pi 4	\$55 + API costs	C#, Java, JavaScript, and Python	Yes	No	High

Figure 3.1.4. Software overall comparison

3.2 – Processor and Controller Research

There are multiple approaches to a final design with regards to the technical specifications and functionality required to integrate real-time image detection. An assortment of options can be considered for the software that will be required for the image detection, but the options vary in their respective requirements. For instance, a software might require an operating system to be installed and accessible. This would force our design to utilize a variation of a computer that can support an operating system.

The implementation could consist of a single board computer (SBC) that can support one of the required operating systems of the image detection software. Per significant PCB design requirements, this would be connected with an MCU mounted directly on the PCB to provide the final build with full functionality. While this design is one of the ways to achieve success, we need to consider if this would be excessive as most SBCs would have the functionality to operate the entire system without a separate PCB.

Another option to consider is to design the PCB around a system on a chip (SoC) versus an MCU. Since an SoC is roughly a midpoint between the capabilities of an SBC and an MCU, this would allow for a more intuitive approach and a smaller footprint. With the ability to run an operating system, a properly selected SoC should be capable of achieving all of the functionality required. Virtually identical to an MCU footprint, this can be mounted directly onto the PCB and would achieve the requirements for a significant PCB design without excessive hardware.

With the recent advancements in real-time image detection software with regards to embedded system technology, there is potential to integrate image detection software into our design without a dedicated operating system. While

an SoC still might be required due to other constraints, such as memory and processing speed, one that is more specific to our design could be considered.

Overall, the goal is a design that is capable of integrating image detection software. In addition, it also must have the ability to operate components such as a camera, servo, actuator, and other components deemed necessary. In doing so, it is ideal if the design of the processing components are as form fitted as possible to our project as it would lower cost, power consumption, and footprint.

3.2.1 – Single Board Computers (SBC)

“A single-board computer (SBC) is a complete computer built on a single circuit board, with all necessary features such as microprocessor(s), memory, input/output (I/O) processor, and peripherals like Ethernet, USB, serial ports, and audio/video outputs.”[1] SBCs tend to be easy to work with and are very useful for a variety of applications. They are a one stop shop for computer processing and graphics formatted into a small package with low power usage. For our use-case, the main appeal to SBCs is that they utilize operating systems. OpenCV is a possible contender for the software that we will be using for image detection, and is one that requires an operating system. Computer vision software is processor intensive. To have the computer determine what the item is quickly, we will want to place emphasis on the processing capabilities of the SBCs while still accounting for their cost. The table below shows a list of SBCs that will be considered.

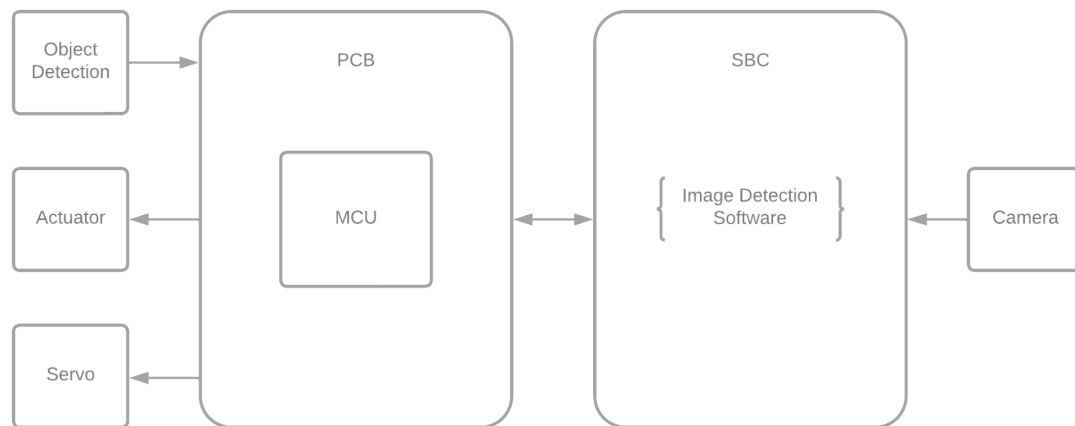


Figure 3.2.1. Single Board Computer to Micro Controller Unit design option

OpenCV

To compare viable SBCs, it is necessary to have a general idea of what image detection software is being considered. Each software will have required hardware specifications to function effectively. Solely for the purpose of the following comparisons, OpenCV is being referenced as the software we are trying to implement. This does not disqualify any other image detection software options from being used in our final design. OpenCV is being used as the baseline because, from the options considered, it has heavier hardware resource requirements. Hardware that can support OpenCV should also be able to support the other software options.

OpenCV Technical Requirements

Exact technical requirements on OpenCV are difficult to pinpoint but estimated requirements can be inferred via referencing community documentation. OpenCV is a very robust software that attempts to meet the demands of all computer vision. This is excessive functionality and overhead for our use case, so a pruned version will be considered.

One thing to note about OpenCV is that the software, by default, uses a parallel framework. This indicates that more cores and higher clock speed can lead to better computational performance and speed so it will be a focal point in the comparison.

Lastly, with regards to OpenCV, memory constraints need to be considered. OpenCV can be installed with as little as 500 MB of RAM, but for the sake of avoiding complex disc partitions and nuanced errors on installation we will not want to consider anything less than 1GB of RAM. However, even with 1GB, there are some adjustments to make to ensure a smooth installation. The preferable amount is 2GB or more as it will allow for a straightforward and seamless installation of a basic version of OpenCV.

3.2.2 – SBC Options

Name	Cores	Clock	RAM	Cost
Raspberry Pi 3 Model B	4	1.2 GHz	1 GB	\$70
Raspberry Pi 4	4	1.5 GHz	8 GB	\$100
Jetson Nano	4	1.5 GHz	4GB	\$150
ODROID XU4	4 / 4	2.0 GHz / 1.4 GHz	2GB	\$85

Figure 3.2.2. Single Board Computer comparison table

Raspberry Pi

Raspberry Pi platforms are a strong contender due to the popularity of their SBCs. The community surrounding the Raspberry Pi platform is consistently active and there is an abundance of documentation and prior projects that utilize Raspberry Pi devices and their operating system. Included are projects that involve image detection using OpenCV.

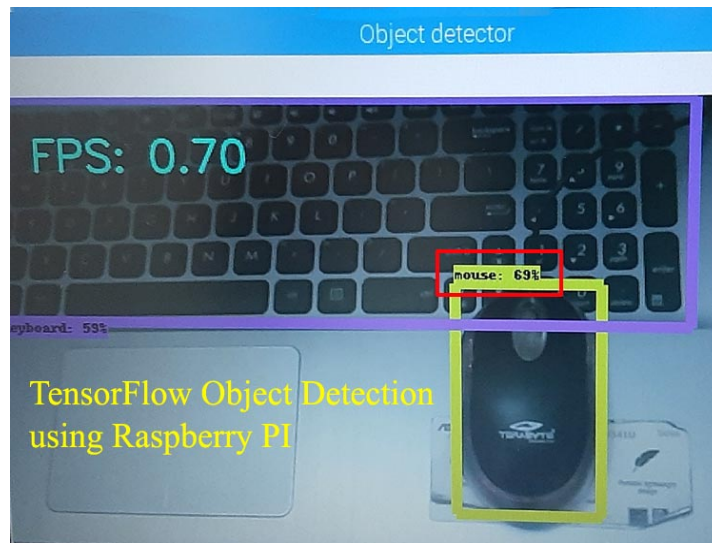


Figure 3.2.3. Image showing object detection using Raspberry PI
(Permission pending)

Raspberry Pi 3 Model B

Out of the four options, the Raspberry Pi 3 Model B is the most cost friendly. It supports a quad-core 1.2 GHz processor which is on par with the other options, though on the lower end of the spectrum. The amount of RAM supported is 1GB. While this is sufficient enough to implement the software, it is lackluster as the recommended amount is 2GB.

Overall, the Raspberry Pi 3 Model B is an option that shines in the documentation and cost technical specifications. It is a Raspberry Pi platform, so the community is strong and at \$70 it is the most cost effective. The CPU clock is slightly below average at 1.2 GHz, but this is outweighed by the difference in cost to the other models with similar processing speed. The biggest drawback is the 1GB of RAM. The benefits of the cost would likely not overcome the shortcomings of the RAM. Given that the Raspberry Pi 4 is also a contender and

has the preferred amount of RAM for only \$30 more, this will likely disqualify the Raspberry Pi 3 Model B from our options.

Raspberry Pi 4

The cost of the Raspberry Pi 4 is justifiable considering the other technical specifications it supports. Like the Raspberry Pi 3 Model B, it has a quad core processor, but the clock speed is higher at 1.5 GHz. This is roughly average when comparing to the rest of the options. It supports 8GB of RAM which is four times greater than what is preferred. While on the surface this might seem like a good thing on the surface, excessive is not better and this is excessive for our design.

The Raspberry Pi 4 is a good option for a multitude of reasons. It is a Raspberry Pi platform, so the community and documentation is a highlighted point for this option. The quad-core CPU clocked at 1.5GHz provides a sufficient amount of computational ability which is on par with what we would like for our use case. At 8GB, the available RAM does meet the preferred requirements, but is excessive. Since we are trying to construct a design as form-fitted as possible with a reasonable amount of overhead, the 8GB of RAM is actually perceived as a negative component from our viewpoint.

Jetson Nano

The NVIDIA Jetson Nano is an option that should seemingly be disqualified immediately due to the cost. On the surface it has similar hardware specifications to the Raspberry Pi 4, but at a cost of \$150. For 1.5 times the cost, one would expect better hardware resources, but the specifications indicate a quad-core CPU with a clock speed of 1.5 GHz. This is the exact specifications as the Raspberry Pi 4. The RAM is 4GB and while this is more in-line with what we would want for our design, one would expect a higher specification rating for the increased price. The main factor in the price difference of the Jetson Nano is the CUDA accelerator. We have to remember that SBCs are a complete computer which infers that they contain a graphic processing unit (GPU). NVIDIA developed a way to take advantage of this component and repurpose it for non-graphical applications. In addition to the CPU, the Jetson Nano can also leverage the GPU's parallel processing capabilities for applications that are optimized with parallel frameworks. Ultimately this will lead to better computational speed. This is why the cost of this SBC is significantly higher than the other options.

The specifications of the Jetson Nano make it a good contender for our design. Similar to the Raspberry Pi 4, it has a quad-core processor with a 1.5 GHz clock speed which is adequate for our needs. The notable component of this board is the GPU and the ability to leverage it for non-graphical computation. At 4GB, the supported RAM is a good fit for what is necessary to implement the

software required. The specifications of this board seemingly make it a great option for our design, but the determining factor will ultimately be the cost. At \$150, the tradeoff for faster computation is likely not worth the additional price compared to other models. A quad-core processor with a quality clock speed, like the Raspberry Pi 4, is sufficient enough to take advantage of the parallel processing that the software is optimized for. At \$50 more, the Jetson Nano cost is not justifiable.

ODROID XU4

The ODROID XU4 has a very well rounded set of specifications. It costs \$85 and features two quad-core CPUs to construct an octa-core design architecture. The first has a clock speed of 2 GHz and the second has a clock speed of 1.4 GHz. In addition, it also has 2GB of RAM available. This is convenient as it meets the preferred amount of RAM without having an excess amount as seen in the Raspberry Pi 4 and the Jetson Nano.

Overall, the ODROID XU4 is an appealing option as it seems the most well rounded to suit the needs for an SBC / MCU design. While it is not the lowest cost, it is only marginally more expensive than the lowest cost option. The extra \$15 is completely justifiable when considering the octa-core architecture that is built in. This setup can leverage the parallel framework built into the software. Also, on average, it has the fastest CPU clock rate when considering the octa-core design versus the other three quad-cores. When taking the mean of all the cores the average clock speed is roughly 1.7GHz. While the Jetson Nano may be able to leverage the GPU to push better computation rates, it is completely unnecessary to consider because there would be no significant improvement in our design. Especially considering the ODROID XU4 has the ability to run octa-cores at a 1.7GHz average clock rate. Considering the RAM, 2GB is the preferred amount and it is the amount supported by the ODROID. Anything more than this would be excessive and anything less could lead to complications with the integration of the software.

At a price point of roughly \$85, the ODROID is cost effective and the hardware specifications rank high amongst the other options. It has the highest computational speed with regards to purely CPU ratings. It has the most cores available, which infers that it will be a great option for parallel frameworks, and it has an ideal amount of RAM for the project. The documentation is not as robust as the Raspberry Pi platforms, but there is still quality documentation with regards to computer vision technology. The slight shortcoming is seemingly made up for in the other features of the ODROID and the budget friendly cost.

3.2.3 – System on a Chip (SoC)

“A system on a chip is an integrated circuit (IC) that combines many elements of a computer system into a single chip.” SoCs are a middle ground between a generic MCU and an SBC. The integrated circuit allows for control, programming and functionality of an MCU without all of the extra bloat that one would find with an SBC. SoCs will contain a CPU and typically have some other components such as RAM, I/O devices and even a GPU. All of the components are packaged into a single chip which allows for the opportunity to integrate this onto a PCB in the same way as an MCU.

SoC vs SBC

The precursor to SBCs were SoCs. What makes SBCs viable is the ability to integrate many computer components onto a single PCB. SBCs utilized SoCs as the foundation in their single board design. Given the small form factor and robust functionality of SoCs, additional components to deliver an out-of-the-box fully functional computer could be added in while still retaining a small footprint. The differences in SoCs and SBCs are the peripherals that SBCs include on board. It is not uncommon to find hdmi ports, plug and play GPIO pins, external memory card slots and more on an SBC. While the benefit of SBCs lies in their ease of use, their downfall is that they are formatted for many use cases meaning they will include a lot of excessive components.

When considering a design with a specific use case, SoCs are more desirable. Because SoCs have robust functionality, a custom PCB can be designed to use this as an advantage. Any necessary components in addition to what the SoC provides can still be implemented, but the unnecessary peripherals that would typically be included in an SBC are obsolete and can be omitted.

Basis for Difference	SoC	SBC
Definition	SoC is an integrated circuit or silicon chip that has all the components fabricated on a silicon chip.	SBC is a whole computer constructed on a single printed circuit Board that contains memory, processor, I/O devices, and other slots.
Components	SoC has all the components integrated on it.	Many peripherals are connected to SBC through slots given on it.
Adaptability	SoC is less adaptable as compared with SBC.	SBC is more adaptable as compared with SoC.
Price	SoC is more expensive	SBC is less expensive

	compared with SBC.	compared with SoC.
Application areas	SoC is widely used in industry as they have a small form factor, less power consumption, and small size. They are used in IoT applications and embedded systems	SBC is used to advance the end product. They are used in IoT applications [and] also used in artificial intelligence.

Figure 3.2.4. Table comparison of System on Chip and Single Board Computer
(Recreated with permission from GeeksforGeeks legal team - legal@geeksforgeeks.org)

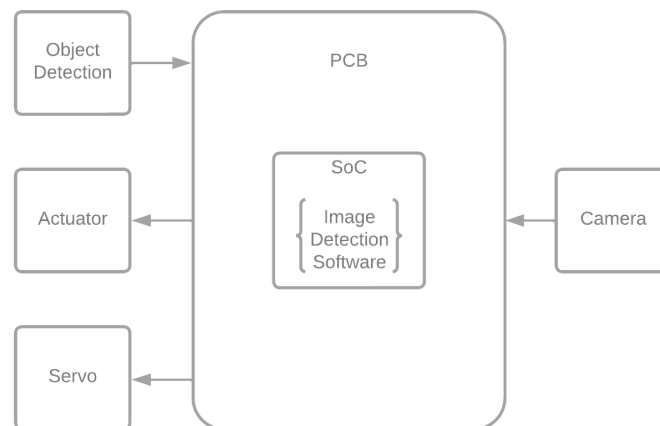


Figure 3.2.5. System on Chip design layout

OpenMV

As with SBCs, to compare SoCs we must consider the software that will be used as a reference point for all possible SoC options. Because SoCs are more fit for custom embedded system designs, we are going to consider an option different from before. OpenMV is an open-source machine vision software technology specifically designed to run without an operating system. This is a more ideal software to consider if opting to go with the SoC design route. There is an understanding that OpenMV is not as capable as an SBC running OpenCV. It is not designed to be. The idea of OpenMV is to take into consideration that

power consumption and size are a limiting factor. If we would like to form-fit our design to meet our specific functionality while considering size and power consumption, then an SBC with OpenCV could be seen as excessive. Therefore, for the following SoC comparisons, we will use OpenMV as the reference software.

OpenMV Technical Requirements

Documentation on exact hardware required for OpenMV is non-existent. However, OpenMV does offer a line of pre-manufactured options which can be referenced to obtain a general idea of minimum SoC requirements. Given that these options are open-source, we can then look to consider the SoCs used in their design knowing that they function well with OpenMV.

Of their products, the lowest SoC specs are pulled from the OpenMV Cam M4 V2. It utilizes an ARM Cortex M4 processor which has a clock speed of 180 MHz, 256 KB of RAM and 1 MB of flash memory. These are likely the absolute minimum requirements that can be considered when choosing an option for the final design. That being said, this is a dated model and there needs to be contingencies for any unforeseen circumstances in the design process. To ensure a quality product will be delivered that meets specifications, a more recent design can be referenced for minimum SoC requirements. The OpenMV Cam M7 uses an ARM Cortex M7 processor with a clock speed of 216 MHz, 512 KB of RAM and 2 MB of flash memory. These will be defined as the absolute minimum specifications that need to be met when considering an SoC.

3.2.4 – SoC Options

Name	Clock	RAM	Flash	Cost
STM32F765VI	216 MHz	512 KB	2 MB	\$22
STM32H743II	480 MHz	1 MB	2 MB	\$22
RT1060	600 MHz	1 MB	16 MB	\$17

Figure 3.2.6. System on Chip comparison table

STM32F765VI

The STM32F765VI is an SoC with the minimum technical requirements for clock, RAM and flash. It is the baseline comparison model that is referenced in the Open MV technical requirements section above. The OpenMV Cam M7 is a design pre-manufactured by OpenMV that integrates this SoC. They provide sufficient documentation with reference to the chip and the peripherals

incorporated into the PCB. This is a benefit as the documentation provided can be referenced in the design process to assist with any associated problems encountered with the SoC or custom peripherals incorporated into our design. In addition, the cost of the STM32F765VI is low and on par with the cost of the other options being considered.

The concerns with this particular SoC are the clock speed of the processor. While it is known that the hardware is sufficient for machine vision algorithms with OpenMV software, the speed at which these algorithms run and the amount of frames per second this SoC can process is important. Our design specifications indicate a target time frame in which an item needs to be sorted. Testing and algorithm development are required to determine exactly how capable this board would be with the autonomous recyclable sorting design, but a processor with a higher clock rate is more desirable.

STM32H743II

The STM32H743II is an SoC that is used in a more recent pre-manufactured design by OpenMV. As with the previously detailed option, there is quality documentation of this SoC as it is integrated into the OpenMV Cam H7 and H7 plus designs. The documentation from these two designs provide quality and detailed references for incorporating this SoC into the custom design for the autonomous sorter. As with the documentation, the similarities to the STM32F765VI continue with the STM32H743II being a low budget option that is comparable to the cost of the other options.

The highlighted technical specification of this SoC is the clock speed that the processor provides. At 480 MHz, the processor speed of this model is roughly two times faster than the aforementioned model. This is a significant improvement and factor in our design as the processor speed will play an important role in the overall speed of the sorter. The main takeaways are that the prices are equivalent and the processor is capable of over two times the speed of the previously mentioned model. Given these facts and that they both have similar benefits with respect to documentation, it is obvious that the STM32H743II is the clear choice over the STM32F765VI.

RT1060

On paper, the RT1060 is the choice that makes the most sense but the shortcoming is the documentation available with regards to OpenMV. The RT1060 is likely to be integrated into the newest OpenMV pre-manufactured model. It is an SoC equipped with a 600 MHz processor which is the highest speed of all of the options being considered. Also, it supports 16 MB of onboard flash memory which reduces the need to integrate an additional expansion component on our PCB design. The other notable specification is that the RT1060 is the most cost effective option at \$17. When considering the RT1060

contains the fastest processor and a significant increase in the amount of flash memory at the lowest cost, it seems obvious that the RT1060 would be the leading contender. However, a possible disqualifying issue with this option is the limited documentation available when considering OpenMV.

In the part selection process we are looking to make confident and calculated decisions to ensure a fully functional product while avoiding as many setbacks as possible. In doing so, choosing parts with quality documentation is an important factor that should not be overlooked. While the technical specifications of the RT1060 are second to none, the documentation is currently lacking with respect to the next leading option, the STM32H743II. Choosing the RT1060 would have risky, and potentially detrimental, consequences if an unfamiliar issue is encountered when incorporating OpenMV. From our point of view, the RT1060 is technology that is at the forefront which is not ideal. While the other technical specifications for the RT1060 are the most qualifying, the limited documentation available is a restricting factor that needs to be taken into account.

3.2.5 – Relevant Technology

Pixy Camera

The Pixy was developed after a successful Kickstarter campaign in 2013 with the purpose of providing vision sensing technology to the do-it-yourself robotics community. It was designed to be a plug and play device that can easily connect with Arduino, Raspberry Pi and Beaglebone microcontrollers and is delivered with software libraries that support those platforms. The Pixy has multiple different ways to communicate with a microcontroller. The communication interfaces include SPI, I2C, UART, UART serial and analog/digital output.

One of the defining features is the vision sensor which allows for real-time object detection. The dedicated software that is recommended for the Pixy is called PixyMon which can run on Windows, Mac OS X or Linux. Once connected via USB, the user can then use PixyMon to begin training the device for object detection. This works by capturing an image with the onboard camera within the software, selecting the portion of the image that you want the device to recognize and then assigning a label to that selected portion. After training the Pixy, it can then enter an object recognition mode to highlight and label objects in real-time.

For object detection, a color-based filtering algorithm is used. During the training process, the software will assign a value to the captured object based on the hue of the object selected. When training to detect multiple objects, different values will be given to different objects based on their color. This becomes useful for instructing a robot to perform a specific task. For example, if the vision sensor

views a blue square the program can instruct the robot to make a left turn. While this provides good functionality for specific tasks and defined visual instructions, the Pixy will have an issue with true object detection.

As mentioned prior, the Pixy uses a color-based filtering algorithm to perform object recognition tasks. The problem with this is when two objects with similar colors are trained. Pixy is looking to distinguish these objects by the value assigned based on their color. It is going to have a difficult time doing so because the value assigned to either object is likely to be similar to one-another. When two objects appear in view of the vision sensor, the way it labels each object will be inconsistent and overlapping. To perform better object detection, integrating a different algorithm like Canny edge detection alongside the color-based filtering algorithm. This would likely improve the accuracy of the object detection, but ultimately this is not what the Pixy is designed to do.

The Pixy is designed to be incorporated into robotic systems allowing for fast real-time decision making. If it were to incorporate a higher resolution object detection, it would sacrifice speed. Knowing this, the developers of the Pixy kept the device simple and user-friendly to appeal to the do-it-yourself robotics community. While there are algorithms available to improve the object detection functionality, the color-based filter algorithm was chosen to maintain simplicity.

JeVois-A33

The JeVois-A33 is an open-source machine vision device that is capable of deep neural network processing. The idea surrounding the development of the JeVois-A33 was to provide the ability to run extremely intensive machine vision, artificial intelligence and deep neural network tasks on an embedded device. After a successful Kickstarter campaign in 2017, the JeVois-A33 was brought to market. It is capable of connecting to a desktop, laptop, Arduino or Raspberry Pi and can be loaded with the latest open-source machine vision software technologies. Specifically mentioned technologies are OpenCV4, TensorFlow, Caffe and Darknet to name a few.

The software options available for the JeVois-A33 give it immensely capable machine vision functionality, but can be very demanding on hardware resources. To meet these demands, the JeVois is equipped with hardware that is not traditionally seen on embedded devices. It has the ability to process up to 31 trillion operations per second because it is essentially equipped with a six-core processor. The six-core processor is made up of a 1.35 GHz quad-core ARM Cortex A7 processor and leverages a dual-core MALI GPU. Between the two components, the JeVois is heavily optimized to perform parallel computing tasks. Many machine-vision software technologies, including the aforementioned software, are optimized for a parallel framework allowing the hardware and software to seamlessly mesh together.

Given that the JeVois-A33 can incorporate a multitude of computer vision software technologies, there are many different algorithms that can be used for object detection. Darknet is a technology that uses a deep neural network to identify many different objects in a cluttered environment. The approach to TensorFlow is to use deep learning to capitalize on object detection. OpenCV4 has many different libraries that can be utilized to incorporate algorithms such as Canny Edge Detection which is a specific method of identifying edges of an object and determining if it resembles an object from a trained database. The JeVois-A33 takes embedded machine vision technology to the next degree with the ability to incorporate a wide range of well documented computer vision software while also being equipped with the hardware to efficiently run the respective software.

The designers of the JeVois-A33 delivered a powerful embedded device in a small package that only takes up 1.7 cubic inches of space. With this, they took advantage of the available computer vision software technologies by allowing them to be easily integrated and utilized. They not only provide the ability to perform simple object detection, but they take this well beyond by also offering many other useful functionalities such as pupil tracking, highlighting specific regions of interest, and many other features. Overall, the device is powerful and versatile and capable of meeting the needs of custom projects, has a small footprint and is delivered at a budget-friendly cost.

	OpenMV M7/H7	Pixy 2	JeVois-A33
Cost	\$65 (M7), \$59 (H7)	\$59	\$59
IDE	Full-featured, cross platform (Mac, Win, Linux)	Just a viewer app	Full-featured, cross platform (Mac, Win, Linux)
Language	Micropython	Not really programmable	Python
Processing Power	60 FPS (M7) 120 FPS (H7)	60 FPS	60 FPS
Memory	.5 MB RAM, 2 MB Flash (M7) 1 MB RAM, 2 MB Flash (H7)	N/A	256 MB
Add-on boards available	Servo, Wifi, motor controller, LCD	None	None
Interchangeable Lenses	Yes	No	No

Interchangeable Sensors	No (M7) Yes (H7)	No	No
Sample Apps	30 covering wide range including deep learning	4 (color and line tracking). No deep learning	30 covering wide range including deep learning
I/O	USB, SPI, CAN, I2C, 3x PWM, Serial, ADC, DAC	USB, SPI, 2x PWM	USB
SD Card	Yes	No	Yes
Lights	2x IR	3x White	No

Figure 3.2.7. OpenMV Cam M7/H7, Pixy 2, JeVois-A33 comparison table (Recreated with permission from Chris @ DIYROBOCARS) PENDING

3.3 – Hardware Tech Research

The following is the technical research of all the possible hardware technology that we might use in this project. Although we most likely will not use all the hardware explained in this section, it gives us an idea of how we want to construct our system for the design constraints needed according to the requirements. This section will cover the investigations of optical, electrical, mechanical, and computational components of the project and the decisions that will most likely be made in the final product.

3.3.1 – Sorting at Recycling Centers Today

When it comes to the hardware used in today's recycling plants to sort the recycled trash, it can be described as a combination of sophistication and primitiveness. The first step carried out by every recycling center is the separation of unwanted items from the recyclables. One common feature across recycling centers nationwide is the utilization of conveyor belts. These conveyor belts transport the recyclables through a series of processes, including exposure to high-powered magnets for separating higher-density metals. The remaining recyclables are then directed through an air vent, referred to as an air classifier, which causes the glass to sink to the bottom while everything else floats to the top. The glass is then passed through a roller and crushed. Therefore, the primary components employed in modern recycling centers are air classifiers and large magnets. However, it's important to note that during the process, some other items may accidentally mix with the glass in the air classifiers. To address this issue, an optical sensor of some sort, along with a robotic arm, could be employed immediately after the air classifiers. This sensor and arm combination

would help identify and remove any unwanted bits of trash that should not be mixed with the glass. This is just the forefront of hardware used by recycling centers today. With our research on different types of technology that could be used to sort trash, we can help advance the recycling agenda that many know nothing about. By considering multiple possible hardware components for our design constraints, we also ensure that no aspect is overlooked and all specifications are met.

3.3.2 – Optical Components

There are many different types of optical components and all are used for various things. For example, a simple camera can capture an image and the pixels focus on capturing color. While another camera focuses on capturing infrared. For our specific designed system, we can consider using optical sensors, near-infrared spectroscopy, and machine vision systems. Although these are broad terms for the hardware we will be looking at, for this initial point of research, it is important to review all of our options to get the full scope of what we want our system to accomplish.

3.3.2a – Optical Sensors

Optical sensors are devices that detect and measure light or electromagnetic radiation of anything that is on the electromagnetic spectrum. They offer several advantages including high sensitivity, fast response times, wide dynamic range, and the ability to measure various properties of light. Three different types of optical sensors are photoconductive, photovoltaic cell, and photodiode. At first glance, you would assume they all do the same thing, but in the world of technology, there are a thousand different ways of constructing a system and a thousand different sensors you can put into it. Here is a table that quickly tells you the difference between photoconductor and photodiode

Photoconductor	Photodiode
The material which allows photoconductivity is known as a photoconductor.	It is a p–n junction device used to convert the light into current.
Examples of materials used in photoconductors are selenium, conductive polymer polyvinyl carbazole, etc.	The materials used in photodiodes are; Germanium, Silicon, Indium gallium arsenide & Indium Gallium Arsenide Phosphide.
These are used in street lights, infrared detectors, camera light meters, etc	These are applicable in consumer electronics devices like, compact disc players, medical equipment & IR

	remote control devices to control ACs & TVs.
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*Figure 3.3.1 Photoconductor vs. Photodiode. - EL-PRO-CUS
(Permission pending)*

For example, a solar panel uses photovoltaic cells to capture light and turn it into energy. The cells are made of a semiconductor material that tries to capture photons. When a photon strikes a cell, it may either reflect, pass through, or absorb which is why solar panels are not 100% efficient. That is also why you always see sprinklers next to solar panels, that rinse off the solar panels to make sure as many photons are hitting the photovoltaic cells as possible. Another device that uses one of these types is a car. If you have a newer car, you may notice that your car's interface dims or your headlights turn on at a certain time of day every day. This would be the photodiode on the top of the car that is excited by light and generates a certain amount of electrical current based on the amount of light it is receiving. So when it gets dark enough outside and the sensor is not producing enough current, your car's built-in computer knows it is time to turn on the headlights or dim the user interface in the car for better vision at night. The last type is not used very often but is different from the other two and is called photoconductive. They are most likely seen in smoke detectors. In a similar principle to the other two, When smoke particles disperse light onto the cell, it undergoes a modification in conductivity, which then activates an alarm.

3.3.2b – CCDs and CMOS

Another type of optical component is called an image sensor. Such as charge-coupled devices, CCDs, and complementary metal-oxide-semiconductor, CMOS, sensors, which are used in imaging systems and digital cameras. They capture light and turn it into electronic signals, allowing the capture of pictures or video. Both CCDs and CMOS sensors have their strengths and weaknesses. For example, CCDs excel in low-light conditions, scientific imaging, and applications requiring high dynamic range. CMOS has lower power consumption, faster readout speeds, and the ability to integrate features like autofocus and stabilization. For these reasons, CMOS are more prevalent in consumer products due to their lower costs and CCDs are found in more commercialized settings. Each pixel in a CMOS sensor has a photodiode to convert light into an electrical charge which is then converted to a voltage signal. This then can be processed and read through multiplexing circuits. The whole process is also done within the same CMOS chip, meaning the enabling of additional features like image enhancement and on-chip noise reduction. CCDs work in a very similar fashion. Instead of a photodiode in each pixel, photons enter the pixel wells of the CCD sensor, which are typically coated with a photosensitive material like silicon. The photons, like before with photovoltaic cells, either absorb, reflect, or pass through the material, generating an electrical charge proportional to the amount of light present. The charges are accumulated in the pixel wells and then transferred to

adjacent pixels through shift registers. Finally, the charges are read out and converted into a digital signal, representing the image captured by all the sensors. Either one of these options is viable to use for our design concept, but it is important to choose something that can be integrated at any moment with little to no problems.

3.3.2c – Near-Infrared Spectroscopy

The next thing we wanted to look into concerning optical component options was spectrometers. Spectrometers are special instruments that are used to measure things by looking at how they interact with light. They can measure light at any wavelength to tell about the composition and properties of different substances. Spectrometers are used in many different areas and, likely, we will not use one of these in our design. But if we do, we will use a method called Near-Infrared Spectroscopy. NIR spectroscopy is a technique that uses the near-infrared region of the electromagnetic spectrum. It can be used to identify different materials based on their unique absorption patterns in close proximity. By shining a NIR light onto an object and analyzing the reflected or transmitted light, our trash bin can determine the composition of the item and determine if it is glass, plastic, or a metal can. But unfortunately, at an average price close to \$5,000, which stems from hardware and software that is very expensive, we cannot see this being a viable option to help determine what piece of trash has been put in our recycle bin.

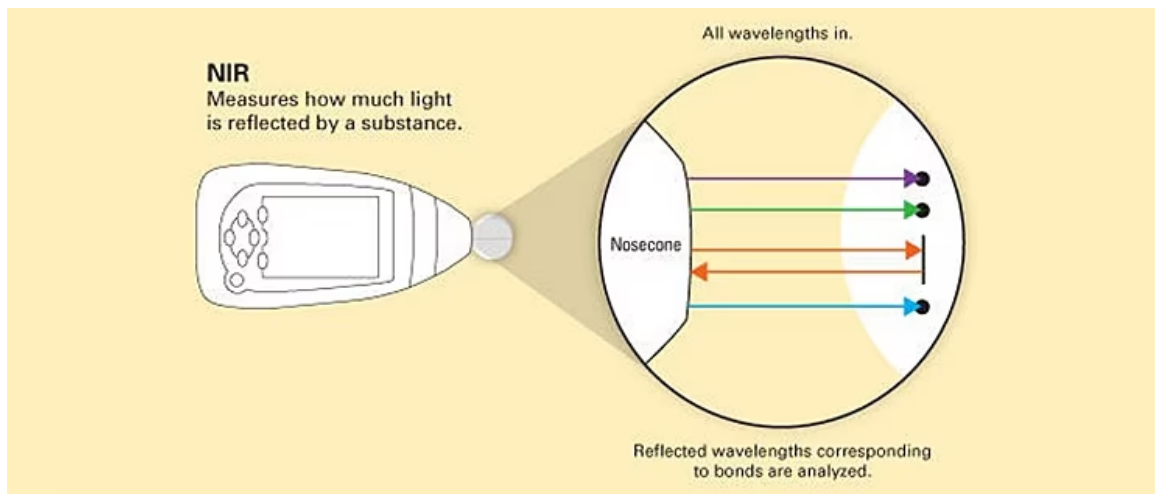


Figure 3.3.2 NIR Sensor. - Thermo Fisher Scientific
(Permission Granted by Greg Lambert)

As you can see in the picture above (Fig. 3.3.2), any type of wavelength can be sent out and whatever the receiver picks up, should give you enough information to get its properties and composition. In our case, glass, plastic, and tin cans all have very different properties. Therefore this would be a very viable option in detecting the type of material coming into our system if the price point for this sensor was not so far out of reach.

3.3.2d – Machine Vision System

The last optical component we want to touch on is machine vision systems. This was touched on in the software research section of this document but it is important to note that this part of the system requires a camera with good quality and quick processing time. This would most likely fit the description of a CMOS camera and a functioning algorithm to analyze the shape, color, and texture of the item. This will most likely be the optical sensor used in our project because it is the most cost-efficient and learning how machine learning systems work would be very beneficial with the never-ending advancing technology the world has today.

3.3.3 – Electrical Components

When talking about the electrical components that are going to be used in this design, it is important to have a stable power supply, efficient wiring, and connectors following the voltage that is going to be used, and solid sensors that also should be able to operate with a small voltage input. Everything I just listed would be the perfect scenario for how a system should be constructed and planned.

3.3.3a – Power Supply

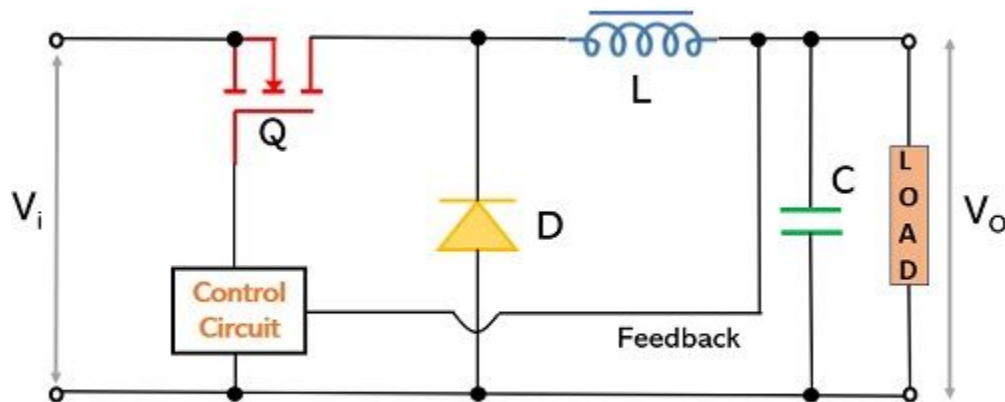
There are many different options when it comes to power supply units or PSUs. But what we want to focus on researching are switching power supplies, linear power supplies, linear regulators, and DC-to-DC. Let's first choose a power supply based on how much voltage we are going to need. In the best-case scenario, we will be able to plug in our system for power so that electricity is never an issue. But just in case that is not an option, we have some ideas. Our first idea was to have a solar panel, hooked up to a battery and then a generic PSU for backup. That is the plan that we want to succeed.

Switching Power Supply

Switching power supplies are very unique. They are specifically engineered to achieve optimal efficiency and have a compact size. They employ a switching regulator that effectively converts electrical power. By utilizing a technique known as pulse width modulation (PWM), switching DC power supplies efficiently regulate the output voltage. This PWM approach enables the utilization of different configurations, such as buck, boost, forward converter, half-bridge rectifier, or flyback, depending on the specific power requirements of the output. While the PWM process does introduce some high-frequency noise, it enables the construction of switching power supplies with exceptional power

efficiency and a small physical footprint. When well-designed, these power supplies exhibit excellent load and line regulation. They have the capability to either increase or decrease the input voltage in order to attain the desired output voltage. Unlike linear regulators, switching power supplies achieve higher efficiency due to the minimal power dissipation of the switching transistor when functioning as a switch. Nevertheless, this switching operation can produce noise, which can be mitigated through the use of filtering techniques.

Now let's talk about some of the designs this power supply can have. Let's start with the buck-switching regulator. This design is the one that produces a DC output signal with a value less than the input value. This is also sometimes referred to as a step-down converter. The operation of a buck switching regulator works as follows, the activation of a transistor through high input pulses, leading to the reverse biasing of the diode. As a result, a current is directed from the transistor to the load via an inductor, while the inductor opposes sudden changes in current based on Faraday's law. This basically means, when magnetic flux or field changes with time, current is produced. This gradual rise in load current is accompanied by energy storage within the inductor. Furthermore, the load current charges the connected capacitor, gradually increasing its voltage to match the supply voltage. Conversely, low input pulses cause the transistor to turn off, interrupting current flow. Without an external supply, the magnetic field around the inductor collapses, inducing a reverse polarity voltage that forwards biases the diode. This enables current to flow through the load via the diode, while simultaneously supplying the load with the stored charge from the capacitor. This process continues until the transistor resumes conduction. Stepping down the output voltage to a desired amount.



Buck Switching Regulator

Figure 3.3.3. Buck-Switching Regulator Design. - Electronics Coach
(PENDING PERMISSION)

While the buck-switching regulator is the most common, let's take a look at a few other designs. The next design we can touch on is the boost switching regulator. This design produces a DC output signal higher than the one provided as input. It is also referred to as a step up converter. You can also combine a

buck and boost model to provide the output current with more or less and the supply input according to the duty cycle. The couple of other designs for a switching power supply but let's continue with a different kind of power supply does not use high-frequency switching.

Linear Power Supply

Linear power supplies are specifically engineered to provide low noise and are renowned for their absence of high-frequency switching. They are preferred in applications that demand outstanding regulation, minimal ripple, low electromagnetic emissions, and exceptional transient response. Linear power supplies can decrease the input voltage to generate a lower output voltage only decrease, unlike the switching power supply. Typically, these power supplies incorporate a sizable transformer to reduce the voltage from an AC line to a significantly lower AC voltage. Subsequently, a series of rectifier circuits and filtering processes are employed to deliver a clean DC voltage. However, linear power supplies do come with certain drawbacks, including their weight, size, and low efficiency. Although everything has certain drawbacks, the ends need to justify the means and there is no shortage of advantages with this power supply.

Linear power supplies offer several advantages that make them a preferred choice in certain design constraints. Their excellent regulation ensures stable output voltage even under varying load conditions, making them ideal for applications that demand precise voltage levels. Additionally, linear power supplies exhibit rapid and accurate transient responses, allowing them to efficiently handle dynamic load variations. These power supplies are known for their reliability and durability, thanks to their simpler circuitry and absence of complex switching components. They generate lower levels of electrical noise and electromagnetic interference, making them suitable for noise-sensitive applications. Linear power supplies also provide more accurate and stable output voltage regulation compared to switching power supplies. Finally, their heat dissipation is more uniform and continuous, simplifying thermal management. Overall, these advantages collectively contribute to the appeal of linear power supplies in various industries and applications. As we are unsure on how we want to set up our power configurations, this could be a viable option to use to power our system.

Linear Regulators

We also wanted to touch briefly on linear regulators. Although they would not be the main power supply component of our system, it could be useful to have to make sure all of our components are getting the necessary amount of power needed to function. Linear regulators are widely used in electronic circuits to provide a stable output voltage despite input voltage and load variations. By adjusting the resistance in series with the load, linear regulators dissipate excess voltage as heat to maintain the desired output voltage. Although their heat

dissipation leads to lower efficiency compared to switching regulators, linear regulators have advantages such as simplicity and affordability, making them popular for low-power applications. They also generate minimal noise and ripple, suitable for applications requiring a clean and stable power supply. Linear regulators excel in line and load regulation, ensuring a steady output voltage even with fluctuations in input voltage or load current. While they offer simplicity, low noise, and good regulation performance, their lower efficiency and heat dissipation must be considered when selecting a voltage regulation solution for specific applications. But in our case we will not be operating above 15V, so the heat will not be an issue if we choose to use linear regulators.

3.3.3b – Solar Panel Usage and Charging

Solar panels are still fairly new technology and their efficiency is not stable enough for high powered systems, but for low power level electronics they are perfect. Let's take a look at solar panels in general to see how they work. Most solar panels use photovoltaic cells, as mentioned earlier, which are made of semiconductor materials, typically silicon. When sunlight hits the solar panel, photons interact with the semiconductor material, causing electrons to be released from their atoms. These free electrons create an electric current when captured and directed through an external circuit. The flow of electrons generates DC electricity. Which then can be used to charge a battery or power certain components. But obviously there are different types. Solar panels can be categorized into three main types, monocrystalline, polycrystalline, and thin-film panels.

Monocrystalline panels are made from single-crystal silicon, offering high efficiency, a sleek black appearance, and high power output. They perform well in limited spaces and under high temperatures. You mostly see these on houses or anywhere that efficiency matters more than cost because monocrystalline solar panels are the most expensive.

Polycrystalline panels are made from multiple silicon crystals, resulting in a slightly lower efficiency and a blue color. They are less expensive and suitable for projects with ample space. These are most often used when someone wants solar energy on a budget.

Thin-film panels are lightweight, flexible, and have a uniform appearance. They are made by depositing a thin layer of semiconductor material onto a substrate. While thin-film panels have lower efficiency compared to crystalline panels, they are useful for specific applications like curved surfaces or building-integrated installations. If we are to use solar panels, it is likely we will try to integrate the thin-film panels due to their mobility, weight, and cost. Here is a good chart explaining the pros and cons of each material thin-film panels can be made with.

SOLAR PANEL TYPE	AMORPHOUS	CDTE	CIGS	ORGANIC PV
Pros	<i>They use less material than traditional panels and their construction makes them extremely bendable and less susceptible to cracks</i>	<i>They produce higher amounts of energy and are also less expensive to manufacture than traditional panels</i>	<i>Their composition makes them comparable in efficiency to traditional panels</i>	<i>They are popular in the building-integrated panel market, making them a more affordable option.</i>
Cons	<i>Amorphous panels are much less efficient than traditional panels</i>	<i>Cadmium is a toxic heavy metal and is necessary for the production of these panels</i>	<i>CIGS panels are very expensive and also use toxic materials in construction</i>	<i>Lifespan is shorter than other panels and they are still quite inefficient with efficiencies of less than 11%</i>

Figure 3.3.4. Materials in Thin-film Panels. - Energy Sage
(PENDING PERMISSION)

Battery

When selecting a battery, it is important to know what type of battery you want and when it comes to mixing solar panels with batteries there are two popular types, lead-acid and lithium-ion batteries. Lead-acid batteries are widely used in solar applications due to their reliability and cost-effectiveness. They come in various types, including flooded lead-acid, sealed lead-acid, and gel batteries. Lead-acid batteries are suitable for a range of solar setups, from small off-grid systems to larger residential and commercial installations. On the other hand, lithium-ion batteries have become increasingly popular due to their higher energy density, longer lifespan, and improved efficiency compared to lead-acid batteries. They are lighter, more compact, and offer superior performance and storage capacity. Specifically, lithium iron phosphate batteries, such as LiFePO_4 , are commonly employed in solar energy systems due to their safety and reliability. We would most likely choose the lithium-ion option if we were to go down this route for power. But this is not the only thing you need to charge a battery with solar. To charge batteries using solar panels, you need a few essential components and processes. First, you need the correct configuration of solar panels that can fit with the specific battery you are going to use. Properly

sizing the panels and connecting them in a series or parallel configuration ensures the desired voltage and current for the battery system. A charge controller is then used to regulate the charging process, protecting the battery from overcharging or excessive discharge. It ensures that the battery receives the appropriate voltage and current from the solar panels. Charge controllers often utilize maximum power point tracking (MPPT) technology to optimize energy harvesting. The charge controller is connected to the battery through wiring connections, allowing it to monitor the battery's state of charge and adjust the charging current accordingly. This prevents overcharging by limiting the voltage and protects against deep discharge. Simultaneously, while the battery is being charged, the system can utilize the solar energy directly for powering electrical loads. The charge controller enables the flow of electricity from the solar panels to the loads, ensuring a continuous power supply. This way, the system optimally uses the solar energy, both for charging the battery and providing immediate power to connected loads. The system could also not use solar energy. We have the option to just power our system with only a battery. The battery could be swapped out and recharged or we could use disposable batteries. This would not be the most efficient way to power our system, but it is good to understand how it would work. For example, we find the highest voltage requirement out of all of our components, and then choose a battery with that requirement. We would then need linear voltage regulators for every voltage requirement that each component could operate on. You would also most likely need step-down regulators if components require lower voltages than the highest requirement. Although this would be challenging, it would not be impossible and would be very similar to using the battery with a solar panel in the circuit.

3.3.4 – Mechanical Components

Lets now focus on the mechanical components. These components are a little up in the air based on the availability once we start constructing the system. But we will definitely need them. When we first took a look at this project we knew that we were going to need actuators, servo motors, possibly a conveyor belt, and compartments to store/frame the whole system. It was also in the talks of borrowing a mechanical arm to sort the trash that way. Of course not forgetting about any of the fasteners and mounting hardware needed to put the whole thing together.

3.3.4a – Actuators

Starting with the actuators, let's dive into how they actually work. Actuators are essential components used in a wide range of applications to control and move physical mechanisms or systems. These devices convert energy into mechanical motion and are available in different types, each designed for specific purposes and operating principles. Electric actuators, powered by electric motors, are particularly notable for their ability to provide precise control over

movement. They can be classified as either linear or rotary actuators, enabling linear or rotational motion respectively. Hydraulic actuators use pressurized hydraulic fluid for generating mechanical force and power, while pneumatic actuators utilize compressed air or gas for rapid movement. The last type, piezoelectric actuators, leverage the piezoelectric effect to achieve precise and quick motion. Actuators are typically controlled by electronic circuits or controllers, enabling precise and regulated motion in a wide array of applications, spanning robotics, industrial automation, automotive systems, and consumer electronics.

After looking at a brief overview of the general different types of actuators, now we can look into what we want our actuator to do. We were planning on having the item of trash funnel into our system and get stopped by a linear actuator. If we were to look at the heaviest item coming into our system, it would be a 16 oz glass bottle full of its respective liquid. Being that a 16 oz glass bottle weighs about 1.5 pounds and 16 oz of water weighs 1 pound, our linear actuator needs to be graded to hold up to 3 pounds to be safe.

Servo Motors

A servo motor, also known as rotary actuator, is a highly utilized motor type in applications that demand precise motion control. It operates as a closed-loop system, continuously receiving feedback to maintain accuracy. Made out of a small DC motor, gearbox, control circuit, and position feedback device, servo motors respond to electrical signals called control signals or pulse-width modulation signals. The control circuit translates these signals into specific positions or angles, causing the motor to rotate accordingly and maintain the desired position. With their closed-loop control system, servo motors ensure accurate positioning and motion control. As you can see below (*Fig 3.3.5*) the feedback loop gives instant feedback to the microcontroller telling it exactly what the motor is doing.

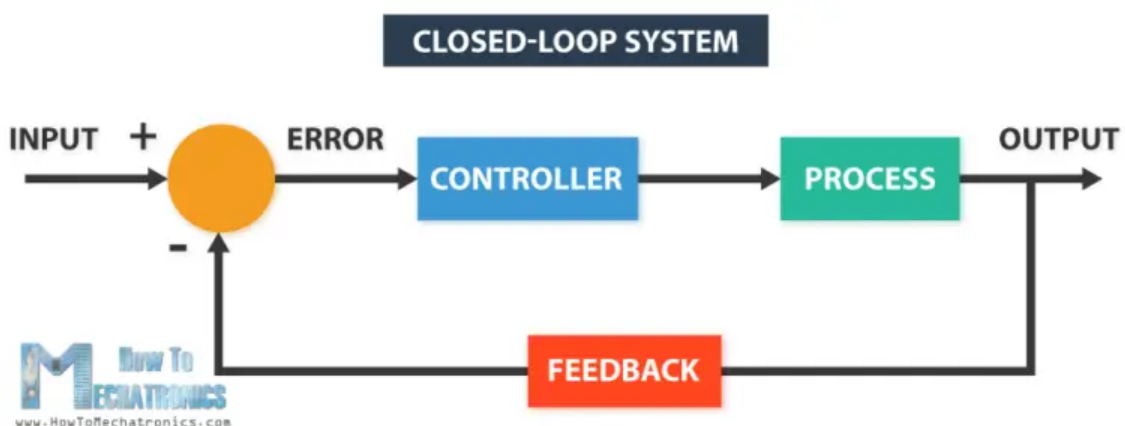


Figure 3.3.5: Linear Control System Closed Loop. - How To Mechatronics
(PENDING PERMISSION)

They are renowned for their high accuracy and resolution, achieving angular positioning within a few degrees or even fractions of a degree. Additionally, servo motors offer a balanced combination of speed and torque, making them suitable for applications requiring both power and precision. Commonly found in robotics, industrial automation, CNC machines, 3D printers, RC models, servo motors excel in tasks that demand accurate positioning, speed control, and repetitive motion. Which is what we will need. Realistically we need the servo motor to go to 3 different points whenever it calls for it to guide the trash into the right bin. Control signals for servo motors are typically generated by microcontrollers or servo controllers, consisting of pulses with varying widths to determine the desired position or angle. Overall, servo motors are versatile, reliable, and essential components in systems that require precise motion control. We plan to use a servo motor for our track system that guides the trash into their respective recycle bin. It will also be hooked up to our microcontroller, which was talked more about in the MCU technology section.

3.3.4b – Conveyor Belts

Conveyor belts are widely used in various industries to transport goods and materials efficiently and automatically. They consist of a looped material that moves along rotating pulleys. Conveyor belts are essential for material handling processes in manufacturing, mining, logistics, and airports. But they can also be efficient on a smaller scale. There are different types of conveyor belts, such as flat belts, modular belts, timing belts, steel cord belts, and mesh belts, each suited for specific applications and load requirements. In our case, we would want the lightest material possible, but also have to have dividers to hold the cylindrical items that are being thrown into our recycle sorter. It would be best for us to use a lightweight rubber band to go around our pulleys and maybe add in the dividers after. Yes, the advantages of conveyor belts include increased efficiency, automation, and reduced labor costs, but regular maintenance is crucial to ensure reliable operation by inspecting, cleaning, lubricating, and monitoring belt tension, alignment, and wear. Overall, conveyor belts might be vital components in modern industries, but in an automated system that needs no human oversight, a conveyor belt does not seem realistic.

3.3.4c – Robotic Arm

When it comes to sorting commercially the only way to do it is using robotic arms. Robotic arms are sophisticated mechanical devices designed to mimic the movements and capabilities of a human arm. They take advantage of something that's called an end effector such as a gripper or suction cup to manipulate and sort objects with precision. We were hoping to get a scaled down version of one of these to borrow for this project, but we had no luck getting one. We planned to use the conveyor belt to transport the items from the entrance, get

scanned by our machine learning algorithm, then get picked up by the mechanical arm and thrown in the correct recycle bin. If a recycling center wished to scale up our design by a factor of 10, it would be a feasible and viable option to emulate the capabilities of an actual recycling center on a larger scale.

3.3.5 – Computational Components

This part was described in detail in the MCU technology section but here I will touch on it briefly. Other than the SBC, single board computer, the PCB needs a communication device to send out what the SBC wants to do. This would be considered the MCU, microcontroller unit. We could use anything from TI, Texas Instruments, that's considered a MCU, for example, msp430fr6989 is a great board with plenty of features that we will most likely not need, but it would still work. Realistically, we will use an Arduino board that fits all of our programming environments and features we will need to have.

Chapter 4 – What is a Standard

Born from the complexity and scale of Engineering problems, standards provide a foundation and guidelines on how to solve these commonly found problems. (1)Standards are extremely useful as they make building equipment simple and modular. The definition of standards at its simplest form is (2)"Standards are published documents that establish technical specifications and procedures designed to maximize the reliability of the materials, products, methods, and/or services people use every day." Standards are designed to be forgotten as they make solving common problems simpler and easier to overcome. Understanding a little about where standards come from will help the team simplify and streamline the process of building reliable and documented solutions to common problems in our senior design project.

4.1 – Standardization History

Standards are found everywhere integrated into our daily lives but reliability and consistency used to be a problem for early engineers. (3)The Greek philosophers are credited with a lot of the foundational mathematical and scientific principles that are used in modern engineering today. The Greek society pioneered ideas such as the pythagorean theorem and area / volume calculations. (4)Ancient Babylonians provided the first documented use of the value of pi as the circumference being roughly 3 times the size of the radius but it was the Greek society which calculated the value of Pi into its precise form of 3.14 today. All these ideas and theories are absolutely integral to our modern

society. They have become so fundamental to our knowledge today that have cemented themselves as an absolute standard. (3)After the fall of Rome, the middle ages became a stagnant and unproductive time in mathematical and scientific history. It was only in the 1700 where science became important to common society. The renaissance provided the footing for the industrial revolution. In the early to mid 1800 both Great Britain and the Americas were agricultural societies. By the late 1800 each of their economies had transformed into power houses of technological innovation. These innovations were so complex and complicated that each idea wasn't contained in a simple theorem or idea such as Pi or Pythagorean theorem. It became evident that these complex and monumental discoveries, designs and ideas needed to be organized and categorized to record societies accelerating progress. To organize, categorize and store these designs, discoveries and methods standards organizations rose from these necessities. Organizations such as IEEE iso and ansi were founded in 1884, 1918 and 1947 respectively. Each organization was founded to create a stable and even floor for technological advancement in their respective domains. As technologies incorporated and built on earlier applications and discoveries, the development team referred to these standardization organizations to provide simple verified and easy solutions for these previously stated common problems. IEEE is an electrical engineering standards organization. ISO is an international standards organization and ASO is an American standardizing organization. The U.S. department of commerce's national institute for standards and technologies(nist) provides a compelling reason to have standards in society.(1) they state "Technical standards keep us safe, enable technology to advance, and help businesses succeed. They quietly make the modern world tick and prevent technological problems that you might not realize could even happen."

Businesses implicitly rely on standards for survival. The rise of standard oil in the 1800 was a direct response to the need for standardization. Before the company standard oil, candle and lighting kerosene was dangerous and volatile as it was refined with different methodology. With these oil refineries not producing oils on a single standard the Likelihood for accidental misuse akin to improper lighting procedures, improper storage, or distribution gave kerosene its infamous reputation. Standard oil artificially imposed a standard on all their subsidiary oil refiners producing a simple uniform and predictable product. The next relevant question after defining what standards are is "where can these modern standards be found?" The first step is defining a problem that needs to be solved and determining if someone has already solved it. Second step would be to try and find a standard which provides a simple and reliable solution to that problem. (1)Some of the tools used for finding these standards are search engines designed specifically to search for engineering standards. Ansi also provides a

portal for some published standards. Older standards might be found in the traditional libraries. The 2 main standards outlined in this project are subdivided into software and hardware standards. Each respective field is vastly different in structure and regulation standards. Out of many pcb design standards the ANSI IPC 2221L documentation is the most straightforward and comprehensive pcb design standards publication. The second is arguably the jedec jeds 47 standards documentation. Jedec is a Japanese organization but is commonly used around the world. The 22221L provides a comprehensive look at the pcb board as a whole. The jeds 47j standard outlines in detail part placement minimum, part quality, and board stress testing standards. A supplement document for the IPC 2221L is the IPC 2222 it is an extension of the IPC 2221L. The IPC 2222 is a standard document called the rigid board design. It greatly expands the physical board design section of the 2221L document.

4.2 – PCB Layout and Design

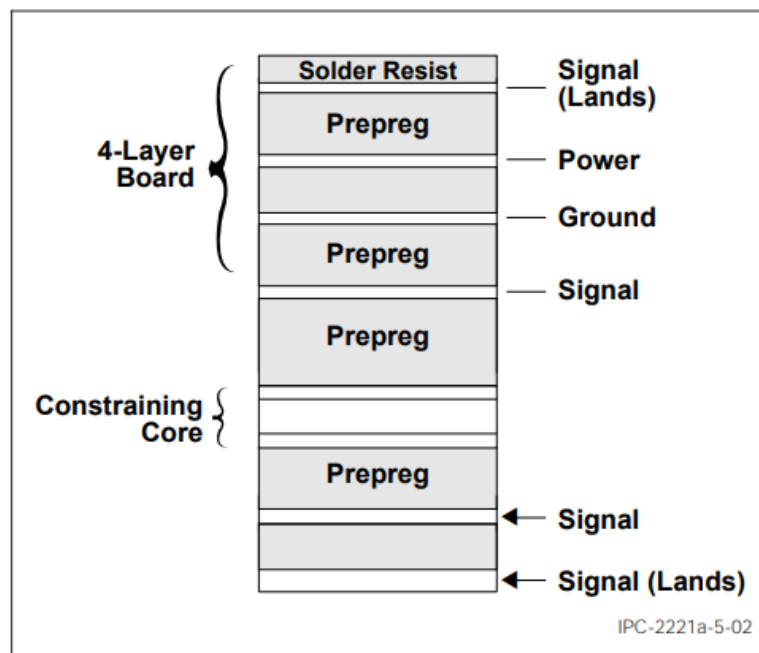


Figure 4.1

To limit cross talk the board should be laid out by component function. The signal processors the mcu and support components and the power supply to name a few. The power supply section should be fitted with high power components. For simpler testing each component or group of components should be capable of isolating. According to the layout design standard modular

components based on function are critical. This modularity makes testing, replacement and part bypass super simple. When the board is laid out the component placement in regards to the functional module boundary is important. The individual component placement helps give the designer insert necessary design changes and board hole placement possible. Board vias are also a consideration. As components might block or otherwise cause trouble with placement and wiring. The high cost components should be of first priority. (9) it is recommended that these high cost components be socketed into the board and given preferential treatment. The methodology behind this standardization principle refrains the perspective of the designer. When the designer lays out a board with this methodology the design life cycle is increased giving better value to the customer. As the board is placed together a part density analysis must be performed to find the ratio of board space to component. The higher the board density the hard it will be to mass produce. Troubleshoot and provide lifecycle support for the board. Because of these adverse effects when designing a board the hidden cost of these problems will increase exponentially. It is wise to stay close to the standard given in the document. (9)It is recommended to stay within a 70% board density. As the board is being designed and analyzed for efficiency and effectiveness it is smart to adjust your design grid to proportion sizes. Latitude and longitudinal grid spacing lines are provided in the standardization document for easy and simple design troubleshooting. Components on printed circuit boards are very sensitive to the environment. Knowing where the board is generally going to be used is a key factor in designing and picking parts for your design. With the sensitivity of the board in mind other intrinsic metering properties need to be considered with part hypersensitive. As control, power and signal wires are being routed along the board it must be recognized that the medium these wires are being laid in is a Semiconductor. It has chances of leaking current off the conductor into unwanted semiconductor material. If the wires are routed at distance from one side to the other. The resistance and inductance of the wire material must be taken into consideration. As the distance increases the wire resistance changes modifying and attenuation the signals and power within the routed wires. If bus wires are routed to close together their individual signal might interact causing crosstalk. Insulation properties in regards to signal isolation and crosstalk suppression are defined in the standards documentation. Components delivering power to different points on the board have their unique sets of instructions and design

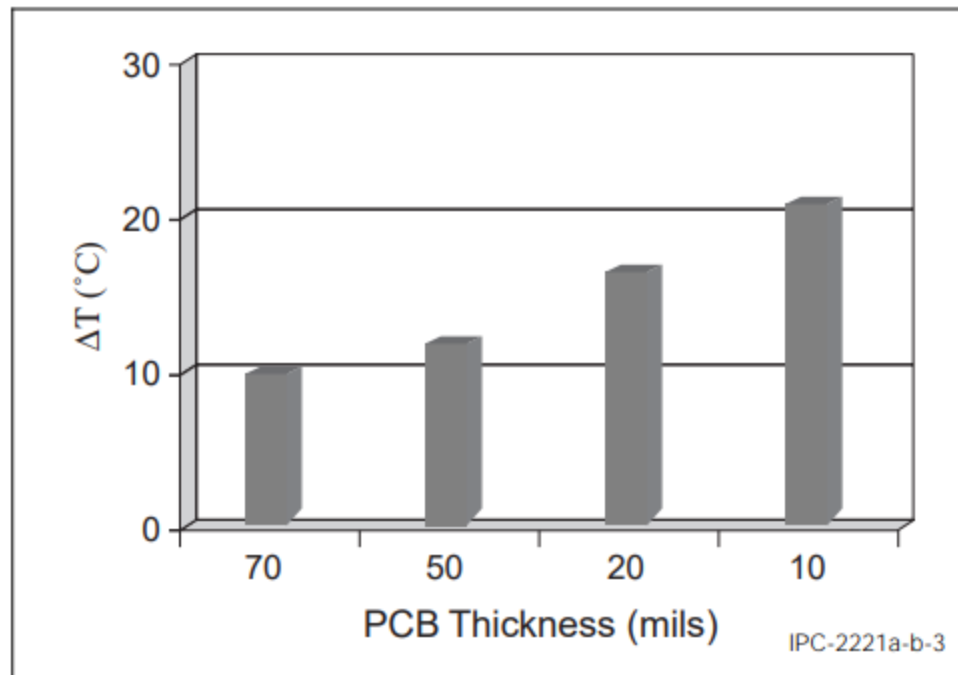


Figure 4.2

guidelines. Since these components work with dangerous levels of voltage and current, extra dimensions of design need to be considered. Some of these standardization guidelines recommend handling procedures specific part spacing dielectric breakdown properties of materials. The power components interaction with the environment needs to be detailed and safety oriented. Some specific components have the required specifications for power protection. The standardization documentation will provide detail for recommended parts designed with the metrics in mind. The pcb board needs to interact with other components outside of its immediate boundaries. The GPIO connection has their own detailed standards specifically dedicated to signal processing and information transfer. The specific details pertaining to part requirement and part placement are found inside that standardization document. Bussing of information throughout the pcb is detailed in the 2221L documentation. Even some board to board information bussing is covered. Some functional parts are inherently incapable of being tested externally. A system called the boundary scan test needs to be implemented across the physical board. Computer register nodes are specially placed in strategic spots to collect information about these untestable parts. In a pincer maneuver between external pinpoint testing and boundary scan testing the board will either autonomously find design errors or identify the location of the error for easy troubleshooting. By far the most

essential aspect of pcb design is thermal dissipation. Thermal dissipation happens all over the board. In the various functional modules heat generation happens very differently. On top of different heat generation rates heat is transferred to the environment differently. (@) The three main modes of thermal generation are conduction, convection and radiation. Since the common pcb does not have access to a heatsink, the pcb design has to employ creative avenues of heat dissipation. Convection is the most straightforward and simple method. Convection directly transfers the atomic vibrations (heat) to the environment, usually air. Both Conduction and Convection are a function of the heat transfer surface area. The standards documentation give useful ways to dissipate heat through each different mode. Convection uses the fluid motion to "scoop up" heat from the surface area of the object. As the heat surfaces to the object / fluid(air) boundary the vibrations in the molecules generate various forms of electromagnetic waves. This is called blackboard radiation. This covers all three modes of heat transfer and the standards documentation covers how to handle and design the circuits and pcb with consideration to each of these transfer methods.

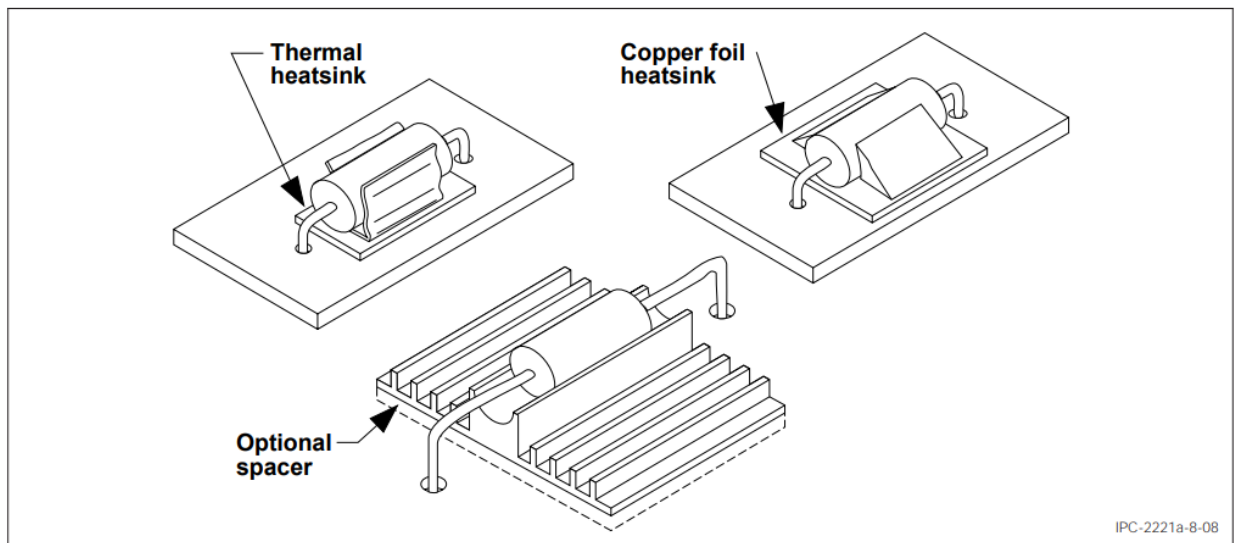


Figure 4.3

4.4 – Software

Software projects are dictated by human capital time organization and implementation order are some of the most important concepts in software development standards. Software at its most basic form is an organized set of instructions that the computer executes to perform a task. Sometimes the tasks are nested to complete a complex system or commands. As such ordering,

organizing and categorizing instructions is paramount. As the software project is planned its development processes are predetermined and guided. The 15288 standardization documentation outlines the complex order and organizations of these development structures. A process is a gradual change in pursuit of an end result. (Miriam Webster). Different processes dominate the way software standardization restricts the scope and narrows down critical ideas and concepts needed to elegantly solve a software challenge. Some of these processes are processes for description, lifecycle models, system lifecycle and quality management processes. Relationships between a system and its commands is a key concept in building efficient and direct instructions. Algorithms allow the software systems to implement highly repetitive and arduous tasks. They are effective and rigorously tested instructions set that perform a highly specific task. Standardization of these processes and algorithms make development simpler. Documentation synchronizes descriptions of each software section. The descriptions are directly injected into the syntax and execution order of the code. Descriptions embedded into the code structure creates a highly parallel symbiotic description execution relationship. The 12207 standardization documentation gives rules and guidelines for universal and easy to read description and commenting of code. With the description standardization the code documentation becomes easily and instantly recognizable due to its familiar standardization structure. Understanding the intended software suite lifetime and projected retirement date helps the development team to clearly picture what system needs to become the core system processes and which system should be secondary and tertiary. The charting depictions and visualizations of these timeliness, core systems and processes is known as the software modeling. A set of development stages can be clearly defined with knowing the end goal, software requirements, customer needs and software system models. As human resources are the key to the development of projects, skills become the commodity to seek in your employees. Setting out methods for fostering and securing necessary skills is outlined in the 12207 documents. Technical processes go hand in hand with employee skill retention. Developing a method for utilizing and deploying human resource skills is an art in it or itself. Organizing skill applications is outlined by the standards. After the development process is completed testing and debugging the software becomes the final step. Reviewing the quality through the project becomes essential for a smooth, easy and simple debugging process. If the core systems were laid out and executed properly bugs will be identified with a brevity. Wise and effective project management and organizations will avert the necessity to fundamentally rewrite the code base when an integrally woven bug is uncovered. Beginning with the end in mind is a

piece of that wisdom found in the quality processes and testing sections in the 12207 documentation.

4.5 – Constraints

There are 3 heavily related project constraints called the triple point. (5) The triple point consists of scope, time and cost. Each of these constraints have a major impact on the project and are highly interconnected affecting each other simultaneously. The first and most important constraint is the scope of a project. What are the major goals and core functionality of the engineering solution? Scope in summarized form, is the range and breadth of the project's functionality. The precise definition is "The project scope is extremely precise and comes with all the necessary information about the final project deliverable. The features and functions identified in the scope have to be achieved in order to call any particular project a success." As the solution set increases it affects the cost and time in an inversely proportional relationship. Both cost and time are interrelated but have lower impact on the triangle because of their greater dependency on the scope. There are exceptions such as a cost increase due to change of components. The change of components could have a negligible impact on scope or timing.

4.5a – Scope

The range and breadth of a project can be difficult to manage, allocating limited time and resources is a factor of constraints. Insight, understanding, and a bird eye view are essential for a manager to manage the scope of the project. When a project is in the planning stages, understanding the application and deployment location is crucial to building an effective project scope. A project scope issue in regards to the Recycle Sorting Machine is material identification. It is difficult and out of the scope of our project to attempt detection of specific material compositions. Instead changing the problem space will dramatically reduce the scale and complexity of the problem. Realizing that most of our target materials are of a specific shape it became easier to identify likely material and target the shape with a high degree of accuracy. Since our design is predicated on shapes and not actual material reduces the precision of the machine. The scope or application goal was not focused material identification but to increase the recycling ratio or material wantonly discarded in the landfills. The philosophy of the project is to make an estimated and instantaneous decision identification of the discarded object to increase the recycles to landfill ratio. It will be a later

sorter which does a more thorough and precise material identification where an instantaneous decision is not of paramount importance. The scope of a project heavily relies on the goal direction and objectives of the project. As the goals and objectives of the recycling project are laid out clearly, the decision scope can begin to take place. A scope aspect of our project is the accuracy rate we will demand of the system. In the case of our accuracy, the rate will be 80% detection and recycle filtration. As the complexity and scope of the project gets easier the time and cost overruns will decrease. One of the main causes of increasing is a phenomenon known as scope creep. The problem happens when we ask to break the previous defined scope metrics. The cause of scope creep comes when the project managers try to "add more value" "what if we did" "the customer might want". As the scope increases budget overruns and deadlines get pushed causing a cascading and rippling effect through the project. With differing opinions and brand new ideas and ways of doing things can cause the project's forward momentum to come to a halt. With good project management and insight as to the needs of the project a manager can untangle the good ideas from the bad ideas and take the excessive and unnecessary bloat work out of the project to streamline the team's focus on the end goal. Scope can be controlled while not stifling outside the box ideas and creative thinking. Although cutting all unnecessary scope creep will simplify the project and help keep it on a trajectory of producing a final end product. The balancing act of scope control is the mark of an effective and well respected project manager.

4.5b – Time

Time is a progression of events which change into the future. Time is basically a progression of events which proceeds after each other changing as they proceed into the next iteration. Time is a tough concept to grasp but with this overly simplified definition of time, it can be used to shine a light into short and long term time management. Managing time and effort is important in everyday life and in the job. When an employee is employed to perform a job it is paramount that they are effective and efficient at their work. There is a saying that goes like this. "Time is Money " this saying directly refers to time as a valuable object to consume, use and manage. Nested within the idea of time management is setting up the order of events which produces a result. Producing a result is not an accident, it requires organization, order and scheduling. Organization should be the first step in managing time as it gives clarity to the constraints and requirements set on project deadlines and delivery dates. Time management entails charting a timeline for completion of the project. Receiving timing feedback is important for tailoring the projected completion deadline.

Organization lays the groundwork for effective time management. Bottlenecks are a direct function of poor time management. If others are relying on a specific job to be completed reorganizing can alleviate this central bottleneck allowing the team to hit timing deadlines and increase efficiency. Time is a progression of successive events. It stands to reason that the core principle of time management is the ordering and organization of these events. Order is a subtle yet powerful driving for which can completely revolutionize efficiency and elegance in obtaining the end result. If swing a bat then through a ball it will hit the ground and stop. If you change the order by throwing the ball then swing the bat you get the ball cracks on the bat and you get a play. If you can effectively parallelize tasks, the timing constraint becomes less of a burden as more of the task can be done simultaneously by multiple workers. If a deadline is unable to be met, reorganizing the problem can decrease the time required to solve the same problem. The final aspect of time management and constraint is scheduling. When time is organized and ordered into highly efficient events synchronizing the highly parallelized system becomes a challenge. Multiple moving parts need to work together harmoniously to create a smooth working and time effective machine. The project manager conducts the team with a schedule. The schedule is how a project manager will categorize and assign tasks to execute the organized events. In our recycling sorter project time is a constant problem. The team needs to take the time to understand every part of the system and begin breaking down the smaller pieces that need to be executed first. The step of breaking down the project into pcb design, camera design, software development, and microcontroller placement are all examples of how organization plays a vital part in managing the team's time constraints. When the individual smaller systems are identified organizing the order in which they should be executed in the event ordering step. Notice that it requires organization to order a complex multi system machine. Once the order of execution is found, completing the development task is next. Scheduling allows each team member to take a section of the project and work on them in order to create an efficient development team. Categorizing and writing down who will do what, when they will do it and how is precisely what scheduling is. When all three pieces come together the development team will be able to hit all their deadlines with efficiency, accuracy and precision while not compromising on quality.

4.5c – Cost

Cost is the final constraint of the triple point triade. Cost is interwoven into the fabric of a project yet nebulous in concept. Cost is the most volatile constraint of a project as it changes come last. Cost is highly dependent on scope and

timing. When any of the aforementioned constraints has a hiccup or is modified in some way the cost is affected directly. As stated previously in the time constraint section "Time is Money" this is an apropos saying greatly revealing the nature of the relationship. As scope creep happens timelines and deadlines are pushed, modified or outright changed completely. These project altering modifications directly change the timing, which increases the project length and finally causes a rise in cost. Costs mount up as workers need to be paid for an increase in time spent on a project. When realizing that a part won't fit a specific application a different part with a different cost must be secured. As each decision has a cost associated it becomes clear why estimating the cost becomes the most volatile constraint of the project. Since money and cost is a finite quantity, budget overruns can become serious problems. If a project runs way over budget the customer will need to agree to paying more for the same promised deliverable or cancel the project. Even though cost usually comes last, considering it upfront will help to alleviate the bite of budget overruns. Knowing how to manage the cost upfront will allow the budget constraint to be met. As the team leader is measuring the cost it is wise to add extra headroom to the cost estimate for those volatile and unanticipated costs. Compounding Cost can be a quiet and nasty surprise for the final cost analysis. Small costs add up and are some of the hardest to cut out of a budget overruns. As opposed to directly cutting an expensive part from a build, cutting an accumulation of small costs requires a change in mindset across all team members. When confronted with the option to buy a small object the offending thought is; "it is only \$xyz". The change in mindset needs to be: do we absolutely need this object no matter the cost? By the end of a project that compounding cost if not changed can be the cost overruns that cancels a project. In regard to our recycling project one of the major cost constraints that we added into the budget was a possibility for a mistake in the pcb design. If the pcb is defective another \$50 would need to be added. Proactively finding and mitigating potential problems such as a defective pcb will prevent some of those nasty surprises from ruining the whole project.

Summary

A common thread throughout project constraints is the project manager is directly faced with the imposition and modifications of constraints on the team. Constraints are guided by the requirement end goal and needs of the customer. To make work on the project simple and streamlined a manager will work with the customer to collect all the requirements and formulate the project constraints from these requirements.

Chapter 5.0 – AI Technology

In recent years, artificial intelligence (AI) technology has made remarkable strides, revolutionizing various industries and transforming the way we live, work, and learn. AI-powered systems, such as language models and intelligent agents, have demonstrated impressive capabilities in natural language processing, pattern recognition, and decision-making. However, as we delve deeper into the realm of AI, it becomes crucial to critically examine its limitations, as well as the advantages and disadvantages it presents. In this section, we will explore the multifaceted nature of AI technology, shedding light on its inherent limitations, while also highlighting its potential benefits and drawbacks. By understanding these aspects, we can better navigate the complexities of AI, make informed decisions about its applications, and ensure its responsible and ethical use in our ever-evolving technological landscape.

5.1 – AI Limitations

[GPTA] My prompt: what are some limitations of AI platforms such as ChatGPT?

Answer: AI platforms, despite their remarkable advancements, are not without their limitations. One of the foremost challenges lies in the lack of genuine understanding and common-sense reasoning exhibited by these systems. While they excel at processing large volumes of data and generating responses based on patterns, they often struggle to truly comprehend the meaning or context of the information. This limitation can lead to incorrect or nonsensical answers, hindering their ability to provide accurate and meaningful responses. Additionally, AI platforms face difficulties in understanding context beyond the immediate scope of a conversation. Nuanced follow-up queries, complex dialogues, or references to past information can prove challenging for these systems, as they often lack the ability to retain long-term context. Moreover, AI platforms can be vulnerable to biases present in the training data. If the data reflects societal prejudices or imbalances, the AI system may inadvertently reproduce or amplify these biases in its responses, potentially perpetuating discrimination, or misinformation. These limitations highlight the need for ongoing research and development to enhance the capabilities of AI platforms and address these inherent challenges. **(ChatGPT response stopped here)**

As ChatGPT mentioned, the main limitation to AI in general is the lack of common sense and understanding of human social understanding. At the end of the day, AI is a technology that needs to be told what and how to think. Current AI platforms are trained using patterns and specified training data. As a result, some of the responses provided by AI could be incorrect and nonsensical. To be

fair, through personal experience with AI, I have found that these limitations only present themselves when the user asks complex or multilayered questions. For example, while testing ChatGPT, I requested a 36-month business plan for my theoretical business idea. Initially, it broke it up into 3 years and considering the number of variables present, it did a stellar job at identifying the variables and creating a hypothetical simulation of said business. The AI model was able to determine an occupancy rate, yearly operational expenses, revenue, and net income. However, I then had a follow up request and asked for the same report but monthly. I wanted each of those 3 years broken up into a month-to-month representation. The result that the AI model provided contained the same info for every month that was shown on the 3-year plan. On the 3-year plan, it said our yearly expenses would be \$150,000. On the month-to-month plan, it said our monthly expenses would be \$150,000 as well. Clearly, this does not make sense and that goes to show the commonsense limitations of AI technologies.

Additionally, as previously mentioned, AI platforms must be trained. They do not have a brain of their own. This makes these platforms extremely vulnerable to bias in the information provided by these technologies. Most developers train these chat bots to avoid answering blatantly opinionated questions to avoid revealing its bias and avoid negative press attention. However, by indirectly asking opinionated questions, you can see that most AI chat bots such as ChatGPT have some sort of bias. During testing, I wanted to explore this topic more and see if I could identify some biased responses. Instinctively, I turned to political questions to attempt to reveal the bias. Initially, I was asking generic questions that were easily identifiable as opinionated and not objective based questions such as, "who was the best president"? The AI platform was able to detect these types of questions and provide answers like these; [GPT-4] "Determining the "best" president is subjective and can vary depending on individual perspectives and priorities. Different presidents are often evaluated based on their achievements, leadership qualities, crisis management, policy impact, and the overall context of their time in office. Public opinion and historical assessments also play a role in shaping perceptions of presidential greatness." **(ChatGPT response stopped here)** As highlighted by that response, the AI bot dodged the question. I then asked it to identify some pros and cons of President Trump's presidency and that's where we were able to identify some bias. As a con, the chat bot listed "handling of COVID-19". This is an extremely biased response because no matter which side of the topic you stand on, there's good and bad on either side. Some people think shutting down the economy was a bad idea and others think it was the right decision to make. The fact that the chat bot considered it a negative shows that the logic and information it was trained on was biased and subjective. I should mention however that the chatbot does a great job at giving you a warning when it thinks the answer being provided could be biased in any way. When asked that question regarding President Trump's term, the first sentence was a warning that read, "As an AI language model, I can provide you with a balanced overview of some commonly cited pros and cons associated with Donald Trump's time in office as the 45th President of the United States. It's important to note that

opinions on these matters can vary widely, and this response aims to present a general perspective.”

A few other limitations of AI platforms include but are not limited to, limited creativity and originality, lack of emotional intelligence, and ethical concerns. Recently, AI has been used to generate art in forms of pictures, and music mainly. These AI platforms can generate new songs using the voices of your favorite artists. Some people see this as a good thing and others see it as an ethical concern. If AI can just generate music from your favorite artist at any moment, you don't need the artist themselves anymore. The artist has been basically stripped of their talent and their contribution to the world. On top of that, AI is generating music using the voices of popular artists which generates revenue. Who is entitled to that revenue? Is it the AI platform since they created the song or is it the artist since they used their voice? The same situation applies to artists who take pictures for a living. In a recent contest, a photo that was AI generated in about 10 seconds was chosen as the winner over the other artist who spent days, even weeks looking for the perfect shot. All in all, if AI continues to advance, we as humans must question the ethicality of it when it comes to content creation. We as humans risk losing creativity and relying on AI technology far too much.

5.2 – AI Pros

[GPTA] My prompt: What are some pros to AI platforms?

Answer: AI platforms offer a multitude of advantages that have transformed various industries and revolutionized the way we interact with technology. One notable advantage is their versatility. These platforms can be trained to perform a wide range of tasks, from natural language processing and question answering to text generation and recommendation systems. Their adaptability allows them to be applied across diverse domains, making them highly valuable in addressing complex problems and enhancing user experiences. Furthermore, AI platforms exhibit scalability, capable of handling many requests simultaneously. This scalability makes them well-suited for applications that require real-time responses or support a significant user base. Additionally, AI platforms are available 24/7, providing uninterrupted service and support regardless of time zone or geographical location. Their continuous learning capabilities enable them to improve over time through regular training and updates, ensuring their performance remains up to date and refined. The consistency offered by AI platforms is another notable advantage, as they provide reliable and consistent responses based on their training data, eliminating the variability associated with human interactions. These pros collectively contribute to the value and widespread adoption of AI platforms in various sectors, making them indispensable tools in the era of digital transformation. **(ChatGPT response stopped here)**

It's no secret that AI technology is extremely useful in multiple different environments such as an educational setting. AI technology has gained a good amount of popularity because of how convenient and intuitive it is. The idea of implementing AI into a chat bot is brilliant. The chatbot idea allows the user to enter questions into a chat box like searching things on google except you get a personalized response. It makes it seem like we are chatting with another person in a way. Accessing this technology can be done from practically anywhere. You can access it from home on your personal computer or on the road through your phone via downloadable application. Additionally, it will be integrated into our traditional search engines such as Bing.

Versatility is another great characteristic of AI platforms such as ChatGPT. This means that they can be trained for specific applications such as natural language processing, question answering systems, image and video analysis, and even financial analysis. The possibilities are endless and will only get faster as time progresses. ChatGPT is more of a generic type of AI platform and does a little bit of everything. ChatGPT can answer questions of all types and provide necessary background information or reasoning. Additionally, it can even solve basic coding problems. All in all, the possibilities, and environments where AI can be implemented are endless.

AI platforms are scalable and can handle many requests at the same time which adds to its versatility point made earlier. Additionally, since AI is essentially a computer, they can work around the clock providing uninterrupted service and support to users around the world. When ChatGPT was initially released for public trial, it was not uncommon to see a message altering that the servers were at capacity. Its popularity was certainly felt by users during this time. As a result, the developers of the platform have substantially upgraded their servers to accommodate for the mass demand for this technology. On top of upgrading their infrastructure, the developers also increased the computational power and optimized the system architecture. This allowed more efficient use of resources from the ChatGPT models. Together, all these changes have drastically improved the user experience and capacity. Nowadays, it's rare to encounter a message denying you access due to server capacity.

Furthermore, AI platforms are always learning and adding more data to their databases. AI is only as good as the information that's made available to it. The developers understand this and make it a mission to update its foundation of information as often as possible. Currently, ChatGPT is trained on information up to September of 2021. It does not have access to information, or events that happened after that. The information made available to ChatGPT isn't updated on a predetermined schedule. Rather, it seems to be randomly updated.

Lastly, AI platforms tend to provide consistent responses and outputs with respect to the training data made available to the model.

5.3 – AI Cons

[GPTA] My prompt: What are some cons to AI platforms?

Answer: AI platforms like ChatGPT, despite their numerous advantages, are not without their drawbacks. One of the significant concerns is the potential for biases in the generated outputs. These biases can emerge from the biases present in the training data, leading to skewed or discriminatory responses. While efforts are made to mitigate biases, it remains a challenge to ensure complete fairness and impartiality. Additionally, AI platforms have limitations in terms of contextual understanding and lack genuine comprehension of the information they process. They may struggle with nuanced queries, miss underlying meanings, or provide incorrect answers that appear plausible but are factually incorrect. Privacy and security are also concerns with AI platforms, as they rely on user data for training and may raise questions about data protection and potential misuse. Moreover, the over-reliance on AI platforms can lead to the deskilling of certain tasks, reducing human involvement and decision-making, which can have social and economic implications. Lastly, there are ethical concerns surrounding the responsible use of AI, including issues related to accountability, transparency, and the potential for unintended consequences. It is crucial to address these cons and implement appropriate measures to ensure the responsible development and deployment of AI platforms. **(ChatGPT response stopped here)**

Artificial Intelligence has impacted numerous aspects of our lives. From autonomous systems and virtual assistants to data analysis and decision-making, AI has showcased remarkable capabilities that were once confined to the realm of science fiction. However, it is imperative to understand the potential drawbacks and ethical considerations associated with such a powerful technology. The cons we will be talking about in this section go hand in hand with the limitations discussed in the previous section so there is not much to add. There is however, one major drawback to AI platforms that I have yet to mention and that is, the abuse or overly relying on the technology. As this technology advances, it will soon be able to do a lot of the specialized jobs we do to the point where humans will no longer be needed. The real problem is that we tend to forget skills and information that we don't regularly use and if as society we are relying on AI for many things humans use to do, then humans as a collective will essentially be useless. We will not have any skills, talents, or knowledge to leverage since AI handles everything. We already see this happening in the education system. Introductory programming courses are taught to students to ease them into programming in most cases, their first ever programming language. In these courses, the coding problems are often simple and are created to get you used to the syntax and basic functionality and structure of a language. These types of problems are ideal for AI models like ChatGPT because it's simple and straightforward. As a result, we are seeing students pass these courses using ChatGPT and not understanding the material

at all. As mentioned earlier, relying heavily on AI can essentially rob us of knowledge and marketable skills. When these students go on to advanced courses such as computer science, they find themselves having a harder time because they don't understand the fundamentals because they had ChatGPT do their assignments. The reason we are seeing students struggle in computer science courses after doing so well in the introductory course is because AI platforms are trained well enough to handle the multilayered programming questions asked in those classes, so students are left on their own to solve them. And without fundamentals, it makes it extremely challenging. However, we are still only in the early stages of AI development and as time progresses, this technology will only get better and soon it will be able to handle those multilayered computer science questions and then our students will be graduating with degrees without understanding any of the material they were studying and that's a gigantic issue for the human population.

Next, we must discuss the abuse that is possible with artificial intelligence. There will always be a group of people that try to negatively exploit all possible avenues to scam individuals. The introduction and popularity of artificial intelligence has drawn that crowd over the AI, and they have certainly been taking advantage of it. AI powered Deepfake Technology allows scammers to create fabricated but realistic audio and video content. Using this technology, they can impersonate relatives and fabricate hostage situations for financial gain. They can also pretend to be a person of authority and deceive the victim into revealing confidential information.

Phishing and social engineering attacks have also been leveraging the power of artificial intelligence to scam people. Social engineering attacks attempt to manipulate people into exposing important private information such as social security numbers or bank account information through emails that appear to be legitimate. Prior to AI, the emails the scammers would fabricate were relatively easy to identify as scam email because they were often very sloppy looking and used incorrect spelling and grammar. As you can imagine, using artificial intelligence solves these issues and allows scammers to produce a legitimate looking email that would fool many people. In conclusion, the misuse of AI technology for scams and fraudulent activities poses significant risks in our increasingly interconnected world. The creation of AI has provided scammers with powerful tools to exploit unsuspecting individuals and organizations. From sophisticated phishing attacks to deep-fake impersonations, the range of AI-driven scams is vast. To combat these threats, we must continue raising awareness about AI scams and promoting digital literacy. By actively addressing the challenges and risks associated with AI scams, we can protect individuals and create a safer and more trustworthy environment for the responsible development and deployment of AI technology.

5.4 – Effects of AI on Learning

[GPTA] My prompt: How can AI positively and negatively impact a student's learning?

Answer: On the positive side, AI can enhance education in several ways. Firstly, AI-powered personalized learning platforms can adapt to individual students' needs and provide customized content and exercises. This personalized approach can optimize learning outcomes by addressing students' specific strengths and weaknesses. Additionally, AI algorithms can analyze vast amounts of data to identify patterns in students' performance, enabling educators to make data-driven decisions and implement targeted interventions. Furthermore, AI can provide real-time feedback and assistance to students. Intelligent tutoring systems can offer immediate responses, explanations, and guidance, fostering a more interactive and engaging learning environment. This instant feedback helps students identify and correct their mistakes promptly, leading to a deeper understanding of the subject matter. AI can also facilitate collaborative learning by connecting students globally, enabling them to share ideas, perspectives, and resources beyond traditional boundaries.

Despite these benefits, AI also presents some potential negative effects on students' learning. One concern is overreliance on AI systems, leading to a lack of critical thinking skills. If students become overly dependent on AI tools for problem-solving or decision-making, they may struggle to develop essential analytical and problem-solving abilities. Additionally, the impersonal nature of AI can limit the development of interpersonal and communication skills, which are crucial for collaboration and teamwork. **(ChatGPT response stopped here)**

Artificial intelligence has the capability to revolutionize learning experience. One of the main problems with the current education system is how generic it is. It assumes that every student will be able to succeed in the same environment under the same conditions as every other student. Unfortunately, that couldn't be further from the truth. In reality, some students excel in the traditional lecture style setting, but others fail because they can't keep up or stay alert throughout the entire lecture. For example, let's assume there's a student in a college setting that takes a bit longer to interpret and write down notes based on the lecture. This student has two options, focus on what the professor is saying and risk missing the chance to write down notes on it or, focus on writing the notes and risk not understanding the material. At the end of the day, it's not fair to the student to make choices from these. AI helps alleviate this issue by providing a personalized learning experience that can adapt to the needs of the student specifically. This can be in the form of teaching style, or content being taught. For example, if the AI technology detects that the student is doing well in one area but struggling in another, the technology could recognize this and change the course to focus on that struggle area.

If we implement AI as a tutor or supplemental learning device, then I think the outcome would be strictly positive. The problems only present themselves when we allow AI to be used as an answering machine. Let's be honest, students already do not want to be in school or complete school related assignments. Giving them a tool like ChatGPT would be detrimental to their learning because it would lead them to take the easy way and have artificial intelligence technology complete their assignments for them. It would lead to a lack in critical thinking skills and fundamental knowledge in our school system. Students would essentially be learning how to use AI instead of learning the material being taught.

5.4a – Negative Impact Examples

1. Over relying on AI for problem solving: The ability to have practically any answer in a matter of seconds could discourage students from developing critical thinking skills. This hinders their ability to independently think and develop analytical skills. Ultimately, this leads to surface level learning only and stops deep understanding.

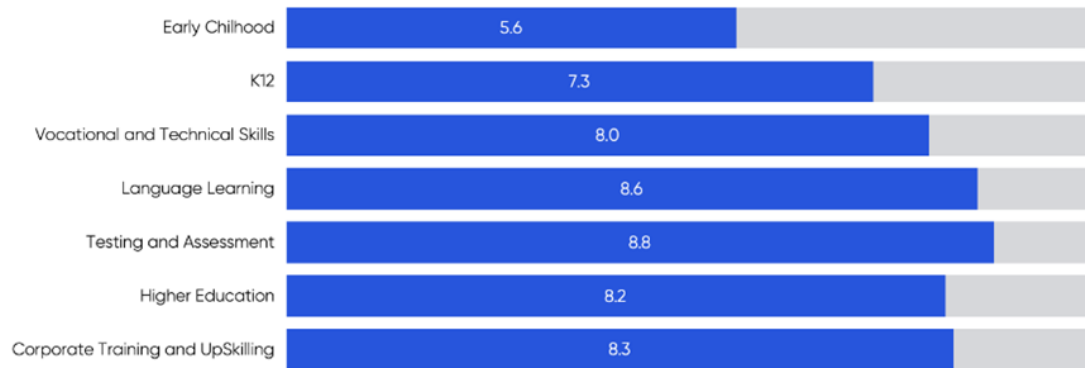
2. Implementing AI into the grading system: AI powered grading systems could offer quick turnaround times on time consuming assignments such as programming homework or even essays. The problem is these AI systems would not be able to capture the complexity and nuances associated with student work. There are many instances where a teacher can understand where a student came from and picture their approach to the question or prompt and award partial credit. With AI, this will be a challenge because of the way the system would have to be trained. It would be difficult to encompass all possibilities into the training algorithm since every student is different.

5.4b – Positive Impact Examples

1. Personalized Language learning: As a native Spanish speaker, I can attest to how complicated it is to learn the English language. Even using the popular language learning programs. AI Powered programs can provide personalized instructions and courses to students. Additionally, it could apply adaptive learning techniques to further assist the student.

2. Supplemental instruction: AI could be implemented into a supplemental instruction program for students at all education levels. Students often struggle with asking questions because they fear asking a “bad” question and facing embarrassment. On top of that, the available tutoring services aren't always convenient to a student with a busy schedule. AI allows developers to create a platform that allows students to ask questions and receive detailed explanations and even videos! Most importantly, it would be available every hour of every day to accommodate even the busiest of schedules.

Assess the impact of AI technologies on different education markets.



Source: HoloniQ, February 2023. n = 464 across both 2019 Aug-Sep Survey and 2022 Aug-Sep Survey

Figure 5.4.2. Expected impact of AI technologies on different education markets.
(PENDING PERMISSION)

Milestones

