Bill Tech Dollar Identifier

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Contents

1. Introduction

1.1 The Problem

In the United States, paper currency cannot be easily identified by those with either visual impairments or blindness. This reality is a uniquely American one, as America is one of the few nations that does not have tactile makers or different sizes in its paper currency [1]. For those who are blind in the United States, many have developed identification systems that require the folding of bills in unique ways [1]. This system works when the identity of the bill is known in advance but it can become messy when the user is given unknown bills. Without the help of another person this is often a difficult task and for those who live alone, almost impossible. In order to aid those with visual impairments who live alone, we propose a desktop device that can identify any paper legal tender in the United States, the Bill Tech Dollar Identifier.

1.2 Our Solution

The Bill Tech Dollar Identifier works by taking a picture of a piece of currency. The user puts the piece of currency on a tray and pushes a button on the physical device. After a brief delay, the device will take a picture of the bill and after a few seconds, the microprocessor is able to correctly identify the value of the bill and output its value from the speaker of the device.

This device differs from mobile app solutions because it does not require a phone to use it. The device follows design standards for ease of use that make it more accessible. The Bill Tech Dollar Identifier only uses a button and power switch as inputs from the user, allowing the user to easily become familiar with the controls.

1.3 Visual Aid

Figure 1 shows a schematic of how our design works. It has a box that encloses the switch to turn the device on and off, the button that sends the command to take a picture and the speaker that uses vibrations to let you know the value of the bill. In addition, it has an arm and at its end is the camera and flash. The bill should be placed on a white surface to make its reading easier.

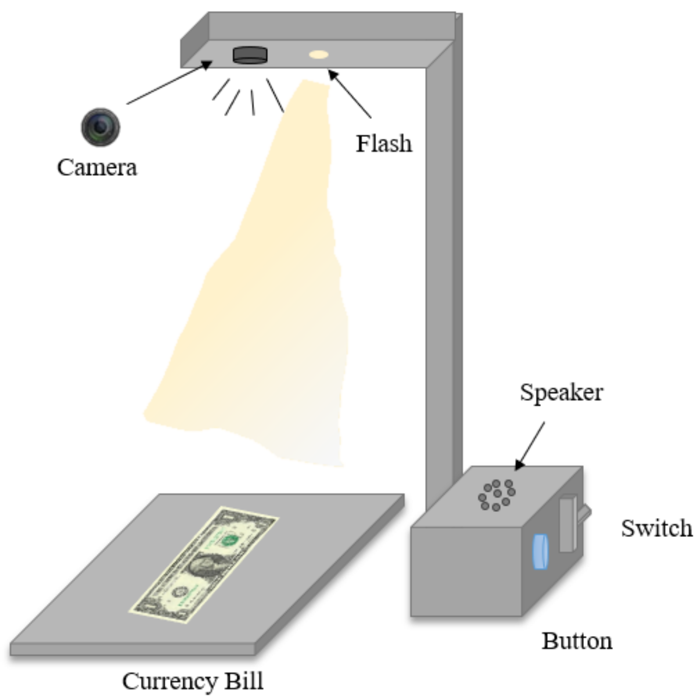

Figure 1. Bill Tech Visual Aid

1.4 High-Level Requirements List

1. The machine is able to correctly identify the bill presented on the loading tray with an accuracy rate of 0.95 and an error rate of 0.03.
2. The machine should produce differentiable audible responses upon identification of different bill types. For instance, a one-dollar bill would produce one beep while a five dollar bill would produce two beeps.
3. The machine should be able to run independently on battery power for at least 1 hour on a battery.

2 Design and Requirement

2.1 Block Diagram

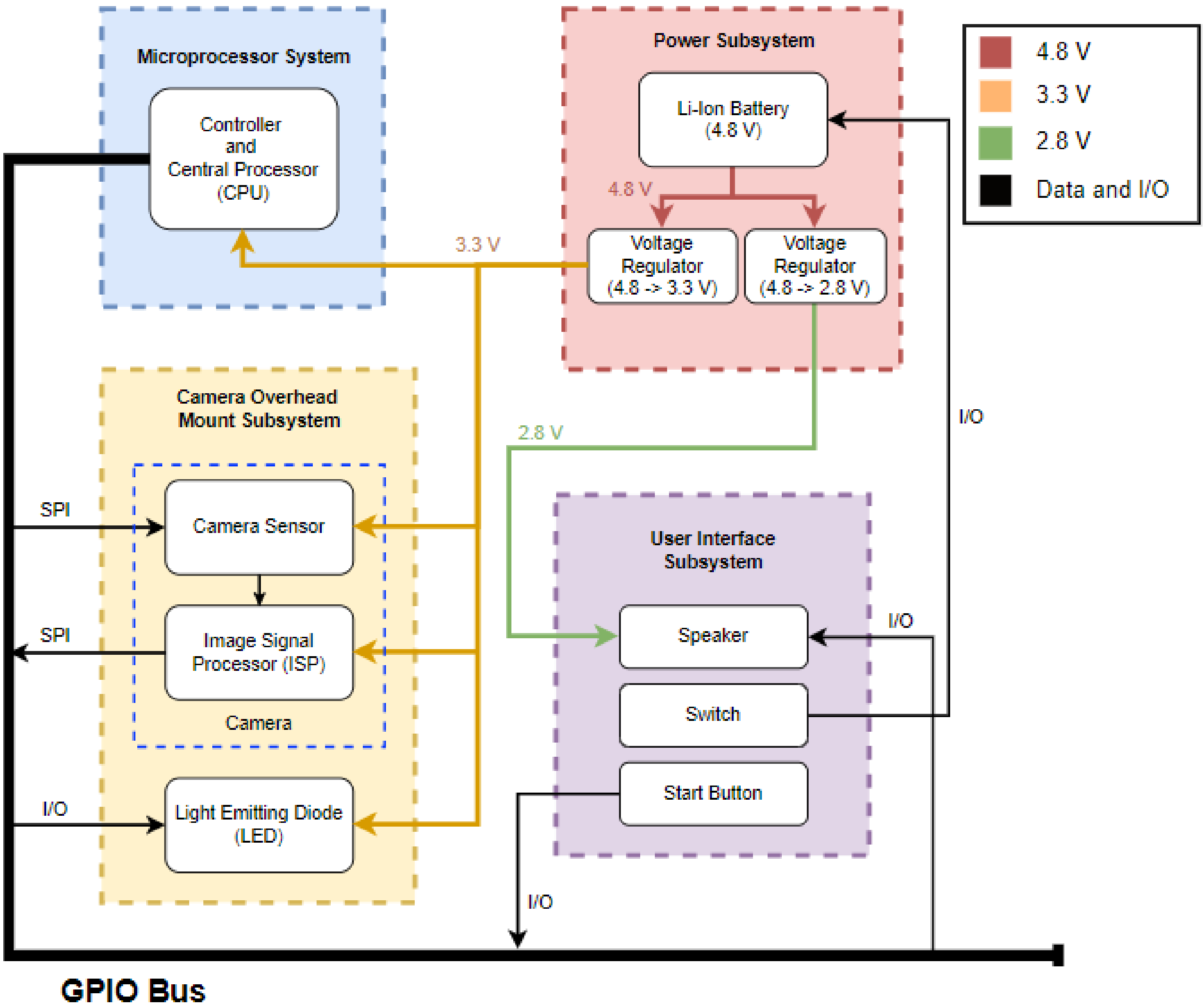

Figure 2. Bill Tech Block Diagram

2.2 Block Descriptions

Power Subsystem

This block describes the power distribution and voltage regulating required to safely run each component. Through the use of a battery and a voltage regulator this block is able to safely power multiple components with varying voltage requirements. This system interacts with the LED, the speaker, the camera, and the microprocessor. This system works in tandem with the microprocessor to both regulate voltage as well as turning off voltage levels to each of the components.

Table 1. Requirements-Verification table for Power Subsystem

Requirement	Verification
Power System 1. The battery provides a 5 V +/- 0.5 %. 2. The battery provides a 3.3 V +/- 0.5 % to the microcontroller, speaker, camera and LED. 3. Protect the circuit if someone connects the battery in opposite polarity.	1. Verification Process for Item 1: (a) Measure the voltage after the voltage regulator using a voltmeter to ensure the voltage is in the range of 5 V +/- 0.5 %. 2. Verification Process for Item 2: (b) Measure the voltage after the voltage regulator using a voltmeter to ensure the voltage is in the range of 3.3 V +/- 0.5 %. 3. Verification Process for Item 3: (a) Connect the battery in opposite polarity and measure the current using an ammeter

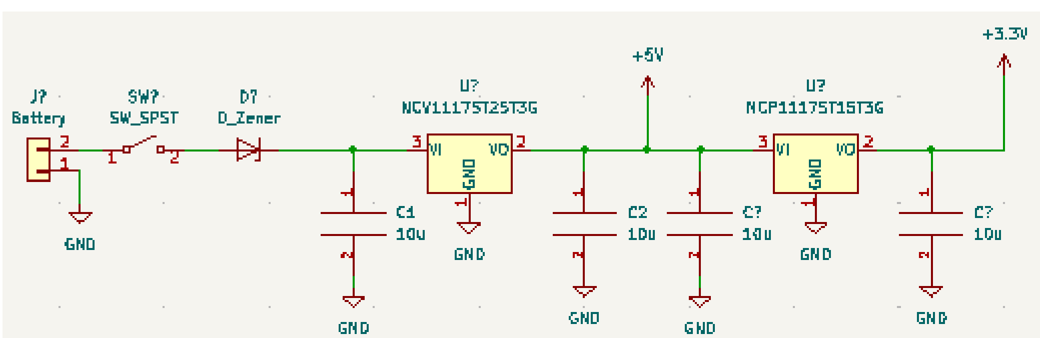

Figure 3. Power Subsystem Schematic

User Interface Subsystem

The User Interface block includes the switch, start button and the speaker. It is through these elements that the user physically interacts with our device. The switch and the button detect the user's inputs and send the signal to the microcontroller. The speaker works as an output, producing differentiable audible responses so the user can identify the bill value.

Table 2. Requirements-Verification table for User Interface Subsystem

Requirement	Verification
Button and Switch 1. Buttons should be debounced allowing for smooth transition between analog and digital signals.	1. Verification Process for Item 1: (a) Attach our mechanical switch to the debounce circuit. (b) Attach oscilloscope leads on either side and the switch. (c) With the circuit powered on, look at the trace once the switch is turned on and off. (d) The image on the oscilloscope should be smooth without any very rampant voltage jumps.
Speaker 1. Speaker should be able to produce at a minimum 7 distinct tones as to distinguish each US bill denominations 2. Speaker should exceed 60 dB in volume	1. Verification Process for Item 1: (a) Attach a 10 Ω resistor in series with the speaker. (b) Set the function generator to 5 V peak to peak. (c) Attach to a function generator and run a sine wave with frequencies beginning at 500 Hz and increasing in 100 Hz increments up to 1500 Hz. 2. Verification Process Item 2: (a) Hear if the speaker can be comfortably heard in a quiet room. (b) This step can be done during step 1 C.

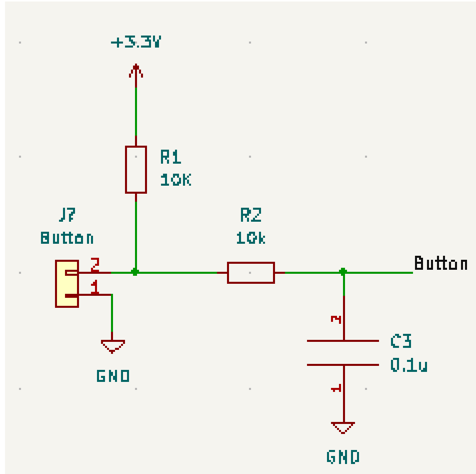

Figure 4. Button Debouncing Schematic[2]

Camera Overhead Mount Subsystem

This system ties directly with the microprocessor and the user interface. When the user presses the start button, with the device turned on, the microprocessors system sends a control signal to the camera and the LED. The LED will then turn on to illuminate the tray, which holds the dollar, and the camera system will take the picture. The ISP on the camera will then process the photo and go through Analog to Digital Conversion and send this data through the GPIO to the microprocessor for image analysis.

Table 3. Requirements-Verification table for Camera Overhead Mount Subsystem

Requirement	Verification
Camera 1. Camera must be mounted high enough as to not hinder loading and unloading the bill by the user but close enough to capture a high resolution image of the bill, at least 0.3 MP.	1. Verification Process for Item 1: (a) The camera must be of sufficient quality to be able to read the value of the banknote at a minimum height of 25 cm. (b) Test the model at different heights. (c) Choose the smallest height that doesn't negatively affect the accuracy of the model.
LED 1. LEDs must be capable of outputting 30 Lumens in brightness sustained at a distance of 25 cm.	1. Verification Process for Item 1: (a) Use a phone app like Lux Light Meter to check light levels in a dark room.

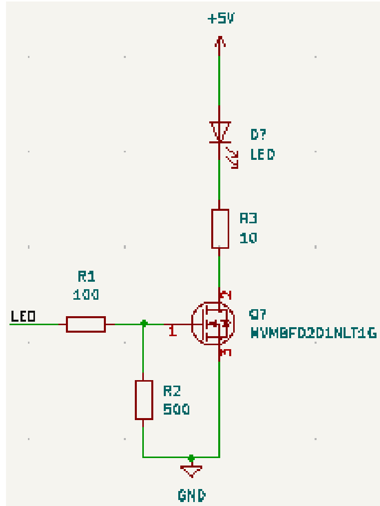

Figure 5. LED Connection Schematic

Microprocessor System

This block takes care of both controlling the individual elements like the LED and the speaker but also performs most of the image analysis. This system will have an image processing model loaded on its flash memory and will use this model to identify bills. After image processing is finished, signals are sent to the speaker so that the user can know the identity of the bill.

The bill identification will be done using a multi-class convolutional neural network trained for image classification. The network will use the basic AlexNet architecture comprising five convolutional layers, three MaxPools, and three fully connected layers[3]. The input layer will consist of a 200 by 200 image and the output will terminate to seven classes. The dataset will comprise images of the full tray with bills laid on top, oriented in different ways.

Table 4. Requirements-Verification table for Microprocessor System Mount Subsystem

Requirement	Verification
Microprocessor 1. Neural Network must be able to fit on a higher end microcontroller with flash memory values ranging from 512 Kb - 1 Mb.	1. Verification Process for Item 1: (a) Evaluate size of neuralnet model as well as image size from camera. (b) Scaledown both image size as well as model complexity. (c) While scaling down both parameters adjust for accuracy until 0.95 accuracy is attained while also being able to fit on the microprocessor.

2.3 Tolerance Analysis

As our device works by taking a picture of a bill and using a model to know its value, making a clear picture is an important component in our project.

The distance between the camera and LED fixture and the body of the machine is important for two functional reasons. As the device is aimed toward the visually impared, the tray, or operating platform, of the machine must be accessible. Therefore the camera must not be mounted too close to the platform itself and allow for adequate space for the user to operate. However, since our machine relies on the camera's image as the input for the classification model, the resulting image must contain enough definition to still perform this classification accurately. Since the resolution of the camera is limited, the fixture cannot be mounted too high either.

In tangent with the camera, the LED's position and illuminance also contributes to the optimal calculation. In order to maintain operatorabilty in the worst case condition—complete darkness—our system must be able to self illuminate approximately 30 lm/m^2 at the platform. A fixture mount too close or too far away may cause overexposure or underexposure of the resultant image respectively.

To get a clear image we have to mount the camera/LED fixture at a minimum of 25 cm from the operating platform, and use an LED with a suitable luminance because the picture quality depends on the bill brightness.

To find the illuminance (lm/m^2) of a surface with respect to a source at distance *d* is calculated with the inverse square law using eq 1.

$$E = \frac{P}{4\pi d^2} \tag{1}$$

Where *P* is the luminous flux of the LED itself and *d* is the distance of source from the surface of measurement. Starting with the minimum distance of 25 cm and a minimum illuminance of 30 lm/m^2, we can plot our distance to a luminous flux graph.

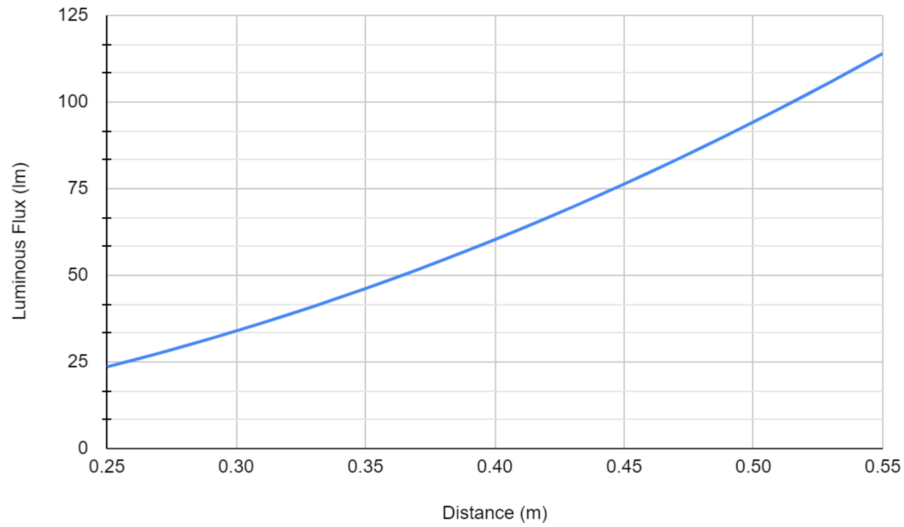

Figure 6: Luminous Flux vs. Distance from Tray

Due to the cost of the camera sensor and memory limitations of the processor, the resolution of the image is 0.3 megapixels or around 640 x 480 pixels with a focal length of 3.6 mm and a field of view of 25 degrees. In order to find the perceived resolution from a given distance, we need to first find the focal pixel *F* which is calculated using the image resolution and the camera's field of view in eq 2.

$$F = \frac{w}{2\,tan(\frac{\phi\pi}{360})} \tag{2}$$

Where *F* is the focal pixel, *w* is the horizontal resolution in pixels, and Φ is the field of view in degrees.

Using the focal pixel we can then use triangular similarity to approximate the perceived resolution, *P*, using eq 3.

$$P = \frac{F\omega}{d} \tag{3}$$

Where *P* is the perceived resolution, *F* is the focal pixel, ω is the width of the object, and *d* is the distance of the object from the camera.

Using our specifications of our camera above and eq 2, we find a focal pixel of 14443.43. Applying this to eq 3, we end up with figure 5.

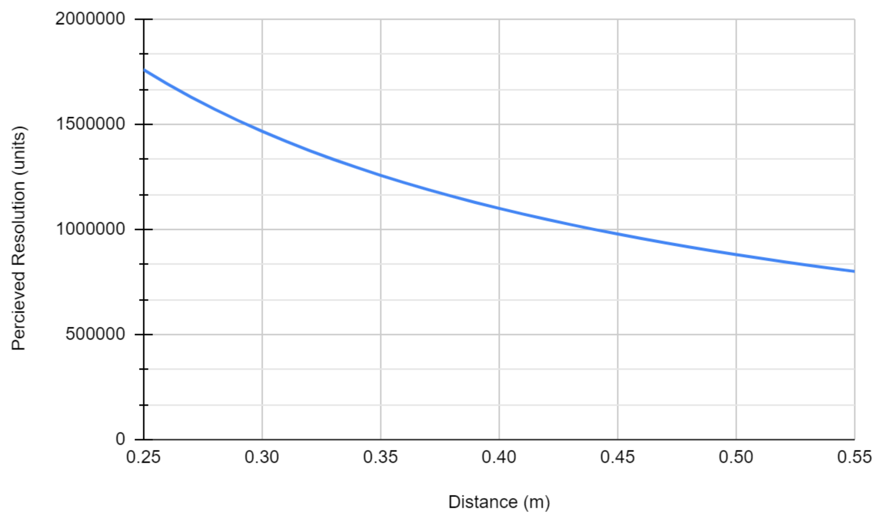

Figure 7: Perceived Resolution vs Distance from from Tray

Since the perceived resolution is not bound to a tangible reference measurement, we can normalize both the illuminance and perceived resolution charts and plot them against each other to find the theoretical optimal distance for the fixture to be mounted. Figure 6 shows this intersecting value to be roughly 0.37 meters from the operating platform. Therefore in order to account for the tolerances, the LED must have a minimum luminance flux of 50 lm to still achieve 30 lm/m^2 on the surface of the tray.

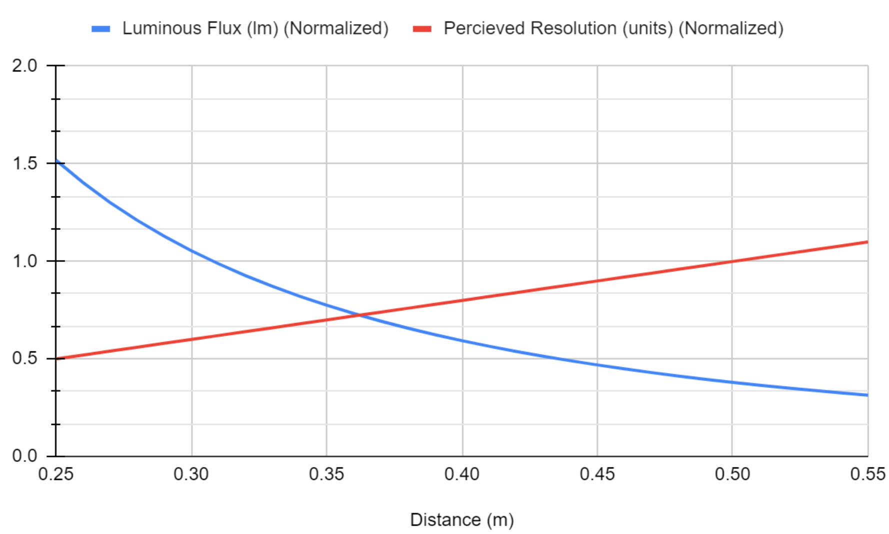

Figure 8: Normalized Illuminance against Normalized Perceived Resolution

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Table 5. Labor Costs

Name	Hourly Rate	Hours	Total	Total x 2.5
Javier Martinez	$40	120	$4800	$12000
Pratheek Eravelli	$40	120	$4800	$12000
Justin Hsieh	$40	120	$4800	$12000
Machine Shop Personal	$50	10	$500	$7500
Total				$43500

3.1.2 Parts

Table 6. Component Costs

Description	Quantity	Manufacturer	Vendor	Cost/unit	Total Cost
OV7670 FIFO Camera	1	OmniVision	Haoyu Electronics	$12.00	$12.00
STM32G0B1KET[4]	1	ST	DigiKey	$6.93	$6.93
ST-LINK/V2 [5]	1	ST	Mouser	$21.25	$21.25
SP-3005Y	1	Soberton	DigiKey	$1.68	$1.68
MAX20405AFOD/VY+	1	Analog Devices	DigiKey	$3.66	$3.66
E2835AWT-00-0000-000A0BH665E LED	1	CreeLED, Inc.	DigiKey	$0.1	$0.1

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Table 6 - Continued from previous page

40-1673-01 Button	1	Judco	DigiKey	$1.72	$1.72
4.8V Battery	1	Duracell	Target	$2.00	$2.00
NCV1117ST25T3G[6]	1	Onsemi	DigiKey	$0.79	$0.79
NCP1117ST15T3G[7]	1	Onsemi	DigiKey	$0.67	$0.67
MVMBF0201NLT1G[8]	1	Onsemi	DigiKey	$0.60	$0.60
Total					$50.93

3.1.3 Grand Total

Table 7. Grand Total Cost (Labor + Parts)

Section	**Total**
Labor	$36000
Parts	$50.93
Grand Total	$36050.93

3.2 Schedule

Table 8. Project Schedule and Task Allocation

Week	Task	Pratheek	Justin	Javier
02/21/22	Design Document	- Design document - Circuit schematics - Order parts	- Design document - PCB design	- Design document - PCB design
02/28/22	PCB Review	- Learn SPI protocol to communicate with camera -Tolerance analysis	- Research image classification models - Tolerance analysis	-Research image classification models -Tolerance analysis
03/07/22	PCB Order #1	- Prototype with development board -	- Refine PCB design - Start training the model	- Refine PCB design - Help training the model
03/14/22	Spring Break	Spring Break	Spring Break	Spring Break
03/21/22	PCB Order #2	- Start programming microcontroller	- Complete the model training	- Complete PCB board soldering - Start programming microcontroller
03/28/22	Individual Progress Reports	- Write individual report - Finish programming microcontroller	- Write individual report - Test model on the PCB board	-Write individual report - Finish programming microcontroller
04/04/22		- Test software operation - Fix possible problems		
04/11/22		-Prepare for the Mock Demo		
04/18/22	Mock Demo	- Implement Mock Demo suggestions - Final assembly		
04/25/22	Demonstration	- Demonstrate project operation - Send final paper to be reviewed - Start working on the presentation		
05/02/22	Presentation Final Papers	Writing and formatting the final paper	Create powerpoint for presentation	Creating visuals and graphics for both final paper and presentation

4 Ethics and Safety

The main ethical concerns come from taking pictures of legal currency. Individuals are allowed to take pictures of currency[10] if the pictures are either smaller than 75% of the size of the original bill or bigger than 150% of the size and the picture shows only a single side of the bill. These pictures also require deletion after use [9].

The model is trained by pictures of bills that will be gathered by the group. This training data is deleted after the identification model is built. The device itself will only need to keep the picture of the currency in memory for the amount of time it takes the model to determine a classification, approximately 5 seconds. After the bill has been identified the picture is deleted, complying with federal standards [9].

In terms of safety concerns this device is operating with both low voltage and current levels which do not pose a risk to any of the group members. LEDs will not be of a strong enough luminance to pose a risk to vision and speakers will not produce a loud enough sound to cause hearing loss. In order to uphold safety standards, members of the group will comply with all safety precautions in the senior design lab as well as carefully following instructions on proper etiquette and technique when soldering components.

We will be following all codes of ethics from IEEE [10] by both upholding moral and ethical standards among ourselves and others, continually considering ethical solutions to problems that do not introduce conflicts of interest, and always trying to communicate with those who are blind or visually impaired to whom this product is intended to help.

References

[1] “How Do People Who Are Blind or Visually Impaired Identify Money?”
chicagolighthouse.org
https://chicagolighthouse.org/sandys-view/identifying-money/ (accessed Feb. 8. 2022)

[2] HACKADAY. “Debounce your noisy buttons”
hackaday.com
https://hackaday.com/2015/12/09/embed-with-elliot-debounce-your-noisy-buttons-part-i/
(accessed Feb. 12. 2022)

[3] NeurIPS “ImageNet Classification with Deep Convolutional Neural Networks”
proceedings.neurips.cc
https://proceedings.neurips.cc/paper/2012/file/c399862d3b9d6b76c8436e924a68c45b-Paper.pdf

[4] Microcontroller STM32G0B1KET6 datasheet
https://www.mouser.mx/datasheet/2/389/dm00748675-2400697.pdf

[5] ST-LINK/V2
https://www.st.com/en/development-tools/st-link-v2.html#overview&secondary=st_all-features_sec-nav-tab

[6] Voltage regulator 5 V NCV1117ST25T3G datasheet
https://www.onsemi.com/pdf/datasheet/ncp1117-d.pdf

[7] Voltage regulator 3.3 V NCP1117ST15T3G datasheet
https://www.onsemi.com/pdf/datasheet/ncp1117-d.pdf

[8] LED E2835AWT-00-0000-000A0BH665E datasheet
https://cree-led.com/media/documents/data-sheet-JSeries-2835-3v-standard.pdf

[9] U.S. Currency Education Program. “Currency Image Use”
uscurrency.gov
https://www.uscurrency.gov/media/currency-image-use (accessed Jan. 28. 2022)

[10] IEEE. “IEEE Code of Ethics”
IEEE.org
https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Feb. 10. 2022)