Autonomous Color Pen Reader

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Abstract

Dyslexia affects 5-10% of the general population, with some estimates going up to 17%. This has a profound effect on productivity of the labor force, as well as creating economic loss as tens of thousands of dollars are spent by families to accommodate their dyslexic children. However, even after their formative years, dyslexic people struggle to hold down a job due to their disability. Furthermore, about 3.4 million people in the US alone are blind.

One of the best investments any dyslexic person can make for their children is a purchase of the pen reader. It is a product for dyslexic, visually impaired, or otherwise handicapped people that reads written text aloud upon scanning text. It utilizes an Optical Character Recognition engine implemented in software to take raw input from the scanner at the front of the pen and cleans it up until it recognizes a character of a certain font. The pen reader then compiles words and sentences out of these characters and outputs and reads them aloud. It can also read aloud the meanings of certain words so that the user can understand unfamiliar words. It can also translate between languages. However, the pen reader's limitations include an inability to read colored text on colored backgrounds. This can get in the way as a lot of jobs depend on reading text whether or not it is of a different color, or that it is on a colored background.

Our main objective is to explore the use of different filters and image processing techniques to improve the pen reader's performance in reading colored text on colored backgrounds, or to design our own pen reader which would be able to read such text. We also would like to include a robotic arm to assist in autonomously sorting objects and placing them where they belong.

1. Executive Summary

The problem we would like to address is the inability of the pen reader to recognize colored text on a colored background. A pen reader is a device that scans lines of text and uses Optical Character Recognition (OCR) technology [3][8] to recognize words and read them out loud to the user. Currently, there are no pen readers known to us that can read any text that is not black on a white background. We will explore the possibility of the creation of a modular attachment or a modification to the commercially available pen reader that can enable the pen to read text no matter what the color is, as well as the design of our own pen reader that can take colored input. We plan to design an electronic filter module using a Raspberry Pi computer to make colored text input readable to the available software inside the pen. We may have to include an OCR engine like Tesseract in the Raspberry Pi as we do not yet have the technical documents of any brand of pen reader to confirm that we can communicate with the pen's scanner. However, this is just a backup plan. We will also attempt to make modifications to the sensor at the end of the pen to better receive colored text input and develop an attachment for that as well. Our solution in the end may use a combination of these, but in the interest of making the solution modular, we will try our best to use only one.

We will also try to create an autonomous object sorter using a robot arm in conjunction with the color pen reader to provide a limited degree of automation to simple sorting jobs. In addition to automating sorting jobs, it will show a handicapped user of the pen exactly how to use it once the pen is on.

2. Opportunity

Our project will help handicapped people by letting them read more text they cannot otherwise read. Around 5-10%, with some estimates going as far as 17%, of the general population of the US is dyslexic[1]. Around 3.4 million people in the US are legally blind[2]. There aren't very many things that are written in black text on a white background except for new books and special labels. Many things, such as product packaging, old yellowed books, logos, and others have their text stylized in a special font or color or printed on a unique background. The pen reader on its own is designed to take different fonts into account, but the problem is that it cannot read color, and so these people have more trouble getting through their workday than the average worker does. By creating a modular attachment to the pen reader that allows it to read color, we can lift that barrier to dyslexic, blind, or workers with other reading disabilities and allow them to work in jobs previously unavailable to them. Any job where you have to sort things by label or involves other form of text (package sorter, warehouse worker, etc) is filled with this kind of work. Dyslexic students and researchers would also benefit from this technology by making it easier to study from old, yellowing books. It will also help those with disabilities with navigation. There is also an opportunity to reduce the amount of money spent on special education for dyslexic people, as well as an opportunity to reduce the amount of stress these workers experience, improving their productivity.

There is also the potential for the robot arm to automate sorting jobs, however this would require a way for it to autonomously move from place to place to continue sorting, etc. It is safe to say this project will not replace any jobs at all at this stage. However, if it is expanded upon, the possibility of automating some unskilled labor is real.

3. Proposed Plan of Action

We propose a number of possible solutions. Our main approach to this problem is the design of an electronic image processor that filters out the raw information from the pen reader's scanner and transforms it into a form that is acceptable for the pen reader to process. The image processing will occur on a Raspberry Pi placed in between the pen reader's scanner and processor.

We can achieve this by first applying a Gaussian filter to the input first to mitigate noise. After the Gaussian filter stage, we will implement a differential filter (edge detector) in software in order to sense sharp changes in color and intensity between pixels and create a black and white image based on that. This will create an outline of the text scanned. This is a form of image edge detection. We can then further add a post-processor to the system and fill those edges in with black color so it is easier to process for the pen reader.

Usual methods to detect edges include Canny edge detection [4], image derivative (Sobel Filter) [5], and phase stretch transform [6]. The first two are available in software libraries like OpenCV which we also plan to use. The last is not, however with that capability have been open-sourced. However, we would also like to explore the possibility of using the cosine similarity method [7] to produce edge detection by putting the color and lightness data of a pixel into a vector and comparing two adjacent pixels. A value close to 1 indicates similarity, and thus no change in color, while a value close to 0 indicates difference, and thus a change in color. This method is not available to implement in OpenCV by default, but is fast and easy to implement.

This method has also been used before, albeit not as commonly as the others mentioned, but it was stumbled upon independently by the group and has potential.

As a backup plan we can also design our own pen reader based on a camera and a Raspberry Pi. The Pi's role would stay the same, filtering out color while also having the duty of processing it and converting the text to speech. Open source OCR engines exist such as Tesseract and text to speech conversion is not very hard as open source programs exist for that as well, and we only need to give it proper input and process the output with just an audio amplifier circuit, such as one based around the LM380.

The robot arm portion of the project will also use a Raspberry Pi to communicate with our pen reader by Bluetooth. We plan to use Bluetooth communication to send the filtered image from the scanner so that the robot arm's Raspberry Pi can convert it to text using Tesseract. It would then use its own control software to approach the object read, using an ultrasonic sensor to determine distance from the object, then grab it, using tactile pressure sensors to determine when a good grip has been established, and move it to the place the object belongs to. If the arm senses resistance to movement (uneven pressure output from the pressure sensors), it assumes the place is full and seeks out another place to put the object. If all places are full, it places the object back to its original spot. These sensors mak up the closed-loop control portion of our project.

3.1. Project Components

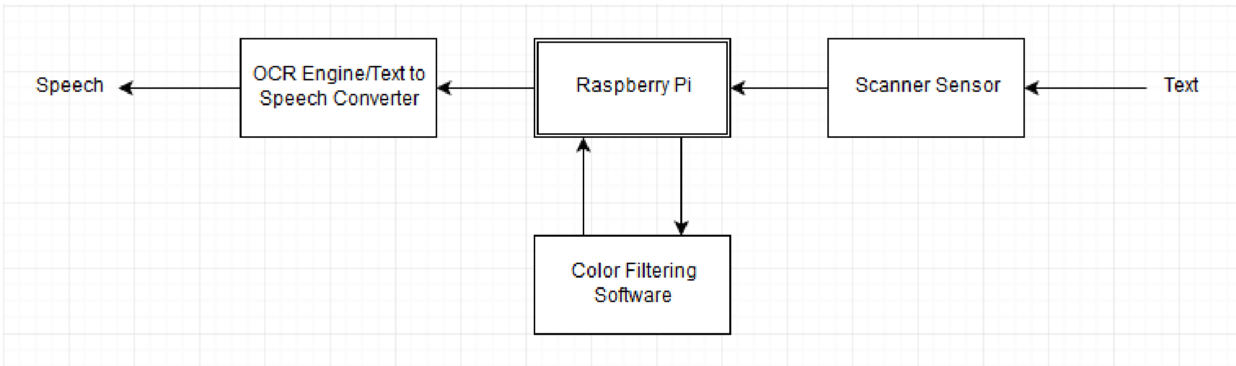


Figure 1 – General Hardware/Software Diagram of Color Pen Reader

Figure 1 shows the most general workings of our color pen reader project. The scanner receives text from the page, sends it to our Raspberry Pi, and gets filtered. This goes back out of the Raspberry Pi and goes to the pen's processing unit to convert to text that is usable by the text to speech converter. It then outputs the result to a speaker in the pen.

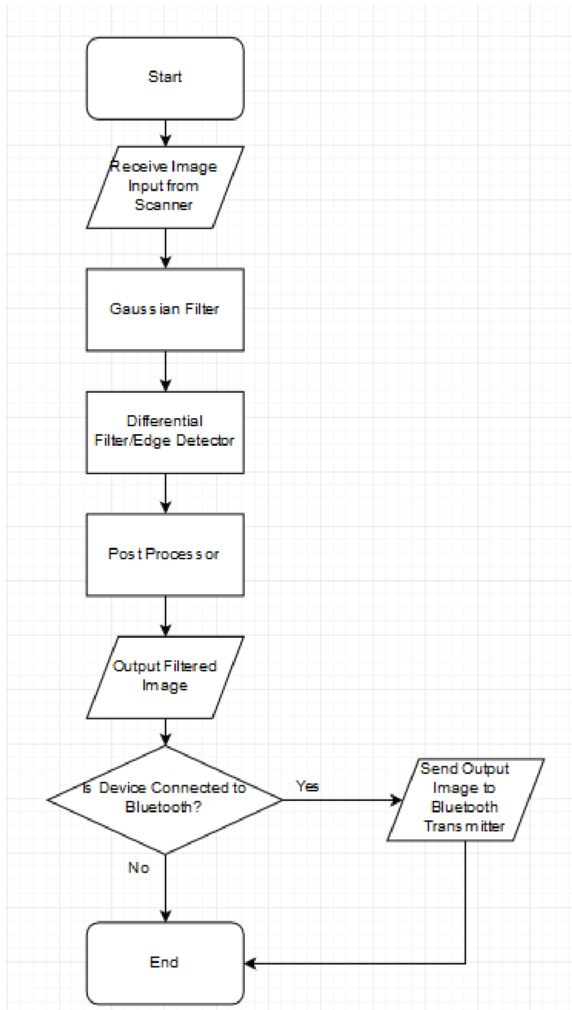


Figure 2: Color Filtering Software Workflow

Figure 2 shows a description of how the color filtering software works. The Gaussian filter cleans up noise from the image, which then goes into the edge detector. That output is then fed into a post-processor which we will add in order to fill in the edges and clean up the eventual output if the pen reader so requires. The output of the post processor goes back to the Raspberry Pi to be sent to the pen reader's OCR engine for processing into speech.

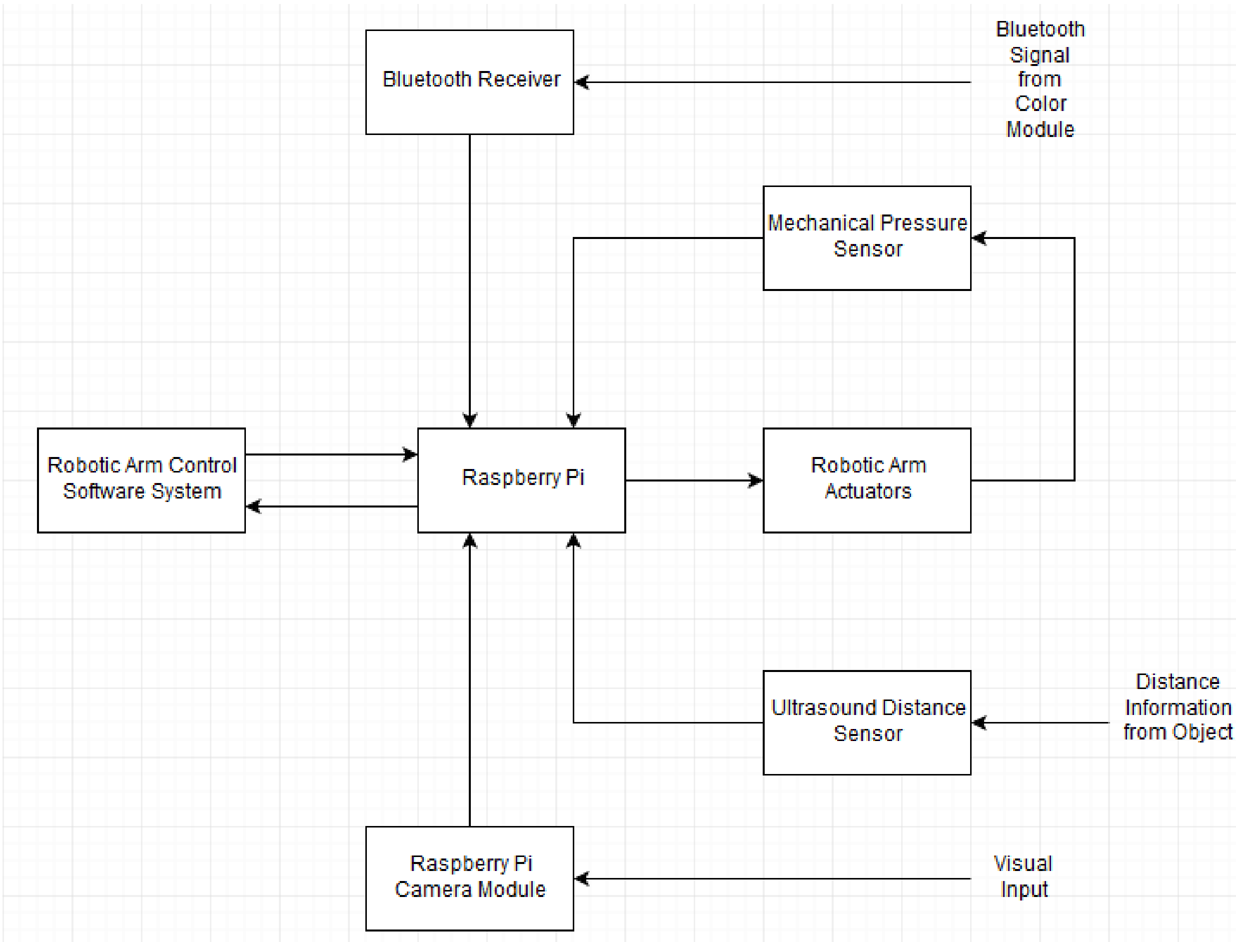


Figure 3: Robotic Arm Control Diagram

Figure 3 shows the workings of the robotic arm portion of our project. The Control Software takes in inputs from the pen reader speech, the distance sensor, and the pressure sensor. Its output is the desired position of the robotic arm. The robotic arm has self-contained control circuitry embedded into it so that the desired position is maintained. The pressure sensor is a negative feedback that tells the control software when the robotic arm actuators have a sufficient grip on the object, while the ultrasonic sensor acts as a negative feedback from the environment to the control software to tell it when it is close enough to the object so that it can begin the gripping process. This is a closed loop control system where the controller is the robotic arm control software. Likewise, the pressure sensor can also act as a negative feedback for when the object that the robotic arm is gripping encounters resistance to movement, as when there is resistance, there is a mechanical pressure exerted on the object, which exerts mechanical pressure on the pressure sensors. In this case, we can compare the current pressure with the pressure felt by the arm from when it first gripped the object, and if it exceeds a certain threshold, try another spot. If both spots are taken, go back to the original spot and release the object.

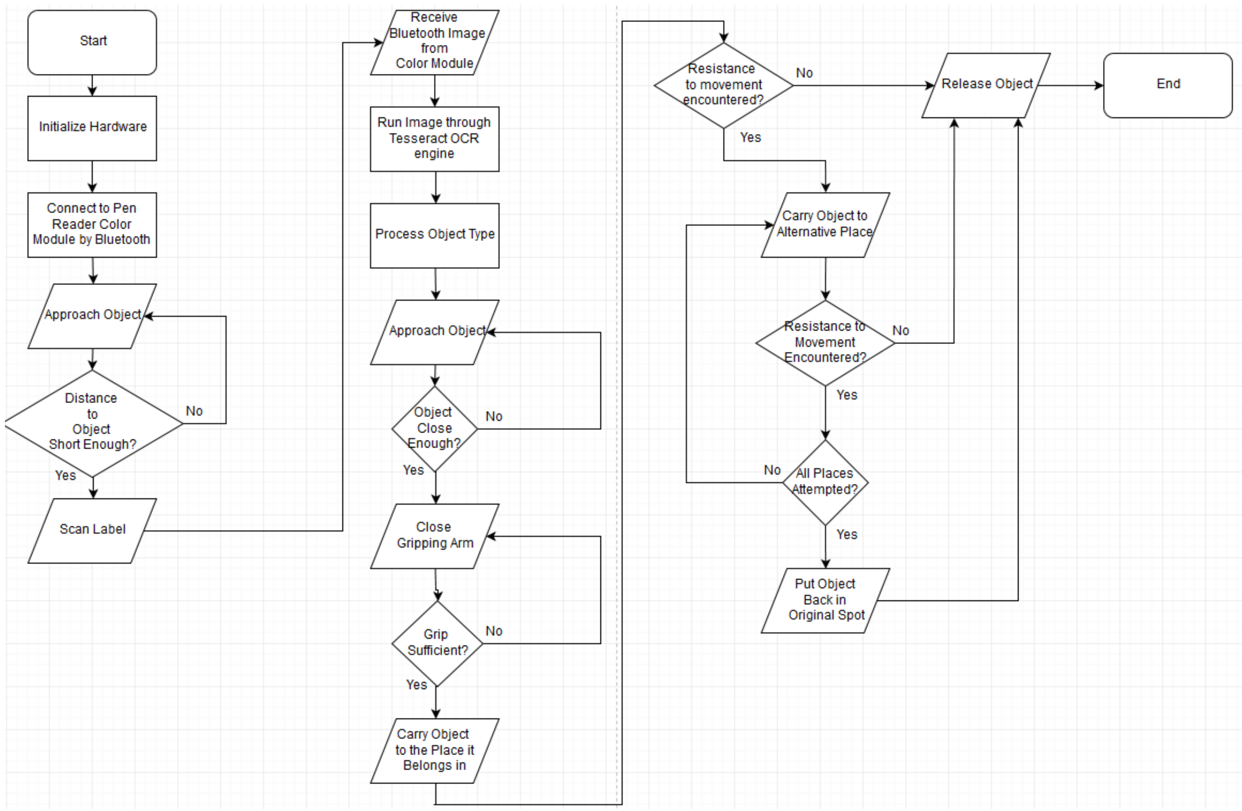


Figure 4: Robot Arm Control Software Workflow

Figure 4 shows the process of the control of the robotic arm. It first initializes all the hardware, including connecting to the pen reader via Bluetooth, then approaches the object to be sorted and scans it, listening for the pen reader’s color module's Bluetooth output. It then puts the Bluetooth output into an open-source OCR engine like Tesseract and converts the image into text. From this it figures out the object type and the place it needs to go. Then, it grabs the object, moving it to the place it belongs in. If there is no space for it, it tries another spot. If all places are occupied, it puts the object back where it was originally. All along the way it receives negative feedback from the environment through its sensors and corrects its outputs accordingly so as not to crash into the object unwittingly or crush it with the gripping arm.

3.2. Hardware/software Requirements

1. Raspberry Pi

The Raspberry Pi will serve as the main computing module of our project. It will provide the processing power to do the image manipulation for the pen reader so it can process colored input. The Raspberry Pi will also operate the control software used to control the robot arm and tell it where to go. As such, we will need 2 Raspberry Pis.

2. Pen Reader

We need a pen reader to modify so that we can focus our efforts on providing it with color reading capability instead of, colloquially put, reinventing the wheel. We will research how the pen works in detail, as well as how it communicates with the OCR engine module. Hopefully we can receive technical documents on the pen so we can expediate this work.

3. Ultrasonic Distance Sensor

This will be used to tell the robot arm how far away it is from the object it is meant to grip. It helps the Raspberry Pi operate the control software it has on board.

4. Tactile Pressure Sensor

This will provide the Raspberry Pi with tactile feedback so that the control software knows when to stop increasing its grip on the object. It will also remember the state of the tactile pressure sensor when it gripped the object originally and compare it with the current state in order to figure out when the object has encountered resistance, signaling that there is no space in the spot it wanted to put the object in.

5. Raspberry Pi Camera Module

This will be used to have the robot arm see where the pen is. Afterwards it will grip it and read the label on an object, process it, put the pen down and sort the object accordingly.

6. Raspberry Pi Microphone Module

This will be used to capture sound input from the pen reader's output so that the control software knows where to place the object.

3.3. Simulation Results

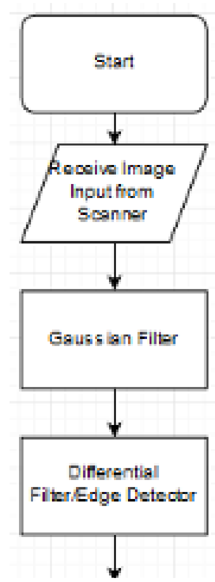


Figure 5: Simulated Section of Color Filtering Software

We have written code in Matlab and Python to create simulations of what we plan to use in the color filtering software of the pen reader. We have implemented the Gaussian filter in our design simulations and variations of the edge detector filter (Figure 5). So far, we have tested the cosine similarity, Sobel, and Canny edge detectors, as well as a combination of Sobel and Canny edge detectors. To thoroughly test each method we wanted to use, we put a low resolution, a medium resolution, and a high resolution version of the image below through each type of filter tested in order to draw the most accurate conclusion about each method and what limitations exist in each method. We created this input in order to test each pure color (red, green, blue) as well as black and white (Figure 6). We also included a mixed color test with low resolution text and high resolution text, with both the color of the text and the background chosen at random (Figure 7). The high resolution picture is 707 x 584. The medium resolution picture is at 355 x 290. The low resolution picture is at 123 x 104. The mixed color input is at 597 x 262.

Figure 6: Pure RGB/BW Test Input

Figure 7: Mixed Color Test Input

The output of the Canny Filter on a high resolution looked the best (Figure 8, 9). Moreover, the Canny filter was implemented in Python and used the OpenCV library. Its edges are sharp and thin, clearly visible, and there are no problems with certain colors. This includes

both outputs from Figure 6 and Figure 7 inputs, however at lower resolutions the output became more and more noisy and unintelligible.

Figure 8: Pure RGB/BW Canny Detector Output, from highest resolution to lowest

Figure 9: Mixed Color Canny Detector Output

The Sobel Filter was implemented in Matlab. Its output was likewise good, however it seemed to also be susceptible to unintelligibility at low resolutions (Figure 10, 11). It also seemed to be sensitive to some colors, with the output being slightly more attenuated than others seemingly whenever a black color was involved, whether in the text or the background.

Figure 10: Pure RGB/BW Sobel Detector Output, from highest resolution to lowest

Figure 11: Mixed Color Sobel Detector Output

A combination of both the Sobel and Canny detector, implemented using Matlab, led to some interesting outputs (Figures 12, 13). On one hand, the output was sharp and very defined at high resolutions. On the other hand, it simply did not work with some color combinations at medium resolutions and lower, making this method not as flexible as the others we have simulated. However, it does open up the door to the possibility of trying other combinations, such as Sobel and cosine similarity or Canny and cosine similarity.

Figure 12: Pure RGB/BW Canny + Sobel Detector Output, from highest resolution to lowest

Figure 13: Mixed Color Canny + Sobel Detector Output

The cosine similarity detector was also implemented in Matlab. Its output was also not acceptable at medium resolutions and below, and it had trouble working out the edges of certain colors and backgrounds (Figures 14, 15). This filter alone is therefore not acceptable for our purposes.

Figure 14: Pure RGB/BW Cosine Similarity Detector Output, from highest resolution to lowest

Figure 15: Mixed Color Cosine Similarity Detector Output

The Canny edge detector had the best performance out of all these filters. Its main advantages over the other methods include a higher resistance to a lowered resolution, as well as a ready implementation in Python, which is already available on the Raspberry Pi 3 without any extra effort. However, its limitations include, as with all the other methods, an unintelligible output at low resolutions. This means we are dependent on the resolution of the scanner sensor of the pen to be sufficiently high enough in order to be able to use the Canny Edge Detector. If the scanner sensor is not powerful enough, we may have to replace the scanner sensor of the pen with a Raspberry Pi 3 Camera Module in order to have the proper resolution. On one hand this will make the end result more expensive, but on the other hand it will also make the pen reader modification more modular and potentially easier to develop. This is because we would only have to translate our output to something the OCR engine of the pen reader understands once. By using the original scanner sensor, we would have to decode the scanner sensor's output signals and then re-encode it so the OCR engine can understand it.

Our next steps are simulations with noise added to the image, as well as simulations using a combination of cosine similarity and Sobel edge detection or cosine similarity and Canny edge detection. This way we can find more limitations of each method and potentially discover previously unknown benefits.

4. Commercialization

We have to introduce the rational benefit on our improved reading pen. Our tech makes the reading pen different. When you scan light color characters with darker background, ordinary reading pens can't recognize any words at all, which means that handicapped people will have a harder time reading, and you still have to struggle on looking up words one by one via cell phone or dictionary. Our project removes the pen reader's color limitation, so you can scan any color of words conveniently as long as there's a color difference between characters and the background.

Our project will target people with reading difficulties such as dyslexia, which is a real time saver to them. Also, those who suffer from the limitation of original reading pens are willing to see our breakthrough that we remove the color limitation.

We should let customers unconsciously accept the concept of improved reading pen. We will plan and implement BTL marketing activities which will include free improved pen experiencing, comparison between the old one and the improved one, distribution of brochures or banners to introduce feature of our product, scanning QR code to let them feel free to follow our social media account which helps us to push further notifications. Once their feedbacks are received through these activities, it will be more efficient to satisfy their needs and leave a good impression.

We'll meet a lot of new problems in commercialization. As we all know, there are too many interconnections between the commercialization and the business operations. However, it seems that we are neither experienced enough in business operations nor do we have enough money to commercialize alone. What's more, our improvement is an integral part of the reading pen. It would be wise if we can cooperate with a reading pen company as we share mutual interest. They own the marketing and have more experience in business operations. Also, we can provide more convenient tech to improve their products, making the cooperation viable. How to maximize the market acceptance is another thing need to take into consideration. We have to admit that it's not an indispensable tool for everyone. It is a specialized product designed for specific people in mind. It cannot be immediately accessed as a platform like a phone app, which means that improved reading pen cannot be spread as easily. In order to speed up the formation of this marketing, we should not only focus on people who have issues on reading but try to create an ambience to people whose English is poor and don’t want to look up words one by one on cell phones and dictionaries. We must convince them that it would be a better choice to use our improved reading pen to fix this issue. Through this guidance, they will remember our product and realize how convenient it is, then gradually accept it.

5. Limitations and further Development:

1. OCR technology’s limitation

Optical character recognition technology which is used in our pen has its limitation in recognizing several parallel character lines. For instance, if the scanner of the pen includes two lines or one line of characters plus portion of other lines in one scanning, then the pen cannot recognize two lines or one specific line. We need to improve this either by restricting the scanning area from outside or improving the algorithm inside the pen. Not only that, but even modern reading pens' success rates range from 81% - 99% [9].

2. Pen’s limitation

What hardware design the existing pen use in scanning port is same as barcode reader. The pen emits light to a surface which is scanned by the user, then the pen receives the reflection of light and process this reflection. We must use a pen that emits only white light to illuminate the text, otherwise the pen cannot scan colorful materials because reflection of colored light on same-colored text would be the same color, however if the background was white, the same color would be reflected too, giving no contrast between text and background. This means if we want to scan colorful materials, the pen needs to emit white color which can reflect any color.

3. Recognition algorithm’s limitation

The precision of character recognition algorithm in existing pen is not high. When we use the pen in scanning some hand-written characters, it cannot recognize them precisely, if at all.

4. Resource limitation

We haven’t got any technical document of our pen reader yet and we haven’t got the pen yet either. We cannot ensure that we can add our own design into original pen’s hardware design easily. If we cannot add our own hardware into its original hardware design, then we need to start the whole pen over and this may need more time, effort, and money.

5. Our scanning module's limitation

If the contrast between text and background is small, the edge detector output will be faint. This will make it hard to fill in the edges by the post-processor in the next stage. We may combine different methods for edge detection and use the output of that, but that may slow the process down. We must find a good balance between filter quality and speed.

5.1. Impact

1. Our reading pen can help people with dyslexics.

It is estimated that 1 in 10 people have dyslexia [1]. Over 40 million American Adults are dyslexic - and only 2 million know it. These people cannot read materials as efficient as people who do not have dyslexia. Our reading pen can help these people solve this problem because our pen can display, can read in high speed and in high accuracy.

2. Our reading pen can help people who are visually impaired.

Our reading pen can read what it scans so that it can help people who are visually impaired to understand reading materials. By listening to reading pen, people who have disability in eyesight can easily understand materials in a normal speed.

3. People who are not familiar with English can also use this pen to help them work.

With our modified algorithm, the reading pen can scan and translate reading materials in a high speed and high accuracy. Then, people who do not understand English can understand English as fast as people who are familiar with English.

4. People who have disabilities in arm or hands can also use our reading pen to control some robotic arms to do some normal action.

Our reading pen has access to our robotic arm. With this robotic arm, people who have disabilities in arm or hands can easily do some actions which are written in the robotic arm's program based on the reading pen's input. For example, some easy lifting-objects job can be done by using our reading pen to scan some letters attached on objects, then one robotic arm can lift that object to another place. With our reading pen and robotic arm, people who have disabilities in arms or hands can also do jobs like lifting or carrying.

When our project is successfully finished, it would make life easier for disabled people, it would improve reading experience and it would make getting jobs easier for disabled people. Our project also includes one part of controlling robotic arm through the input read into the pen. Then, it also can help people do some specific action like lift different things depends on what the pen reads.

5.2. Prior Art

There are many competing technologies like the C-PEN Reader, ScanMarker and Power Pen but they don’t read colored text on colored backgrounds well. We will try several algorithms to solve this problem.

There is no reading pen on the market which uses a robotic arm. Adding this component will enable the input of the reading pen to produce output, such as when reading pen read letter like “bottle”, then the robotic arm can lift bottle in one fixed place and then carry the bottle to another fixed place. This is one specific action and robotic arm can potentially do lots of other things.

6. Project Management Plan

6.1. Research Plan

Our strategy started with researching on OCR technology. This gave us an insight to what it's about and the general uses for it. We then plan on testing the pen we are working with to see how well it works and how it performs in scanning colored text on colored background. Choosing our approach will based on several factors such as: size of pen, technical information, compatibility with filters. We are going to test out increasing the intensity and removing color.

This method is expected to intensify the noise present which could make it harder for the pen to read, so in order to fix this problem, we plan on applying a Gaussian filter. We also plan using an additional filter which would mainly be used for sensing color and intensity changes between each pixels. We will be experimenting with OpenCV to test Canny edge detection and image derivative, or other libraries in order to test phase stretch transform and cosine similarity. We will also research a way to implement a post-processor to fill in the edges detected by the previous filters. In this way the post-processor changes it to a form in which the pen reader can easily process. We plan to use a Raspberry Pi for this conversion.

We will also use a Raspberry Pi for our robotic arm. It would mainly be used for communication by voice with our pen reader, so when the pen reader scans a word, the robotic arm would be expected to pick up the material that was scanned and drop it in a certain position.

6.2. Team and Collaboration

Michael Mordkovich (Project Manager/Hardware/Software Engineer)- A very experienced engineer who has managed several projects, he is well spoken and very organized. He has also worked with OCR technology and has a clear idea of the direction in which the project should go. He will be responsible for making sure the project is delivered on time, within scope and within budget.

Haoran Wu (Hardware / Software Engineer)- Haoran has worked on different projects which required use of Field – Programmable Gate Arrays (FPGA) and microprocessors. This experience will be useful in our project.

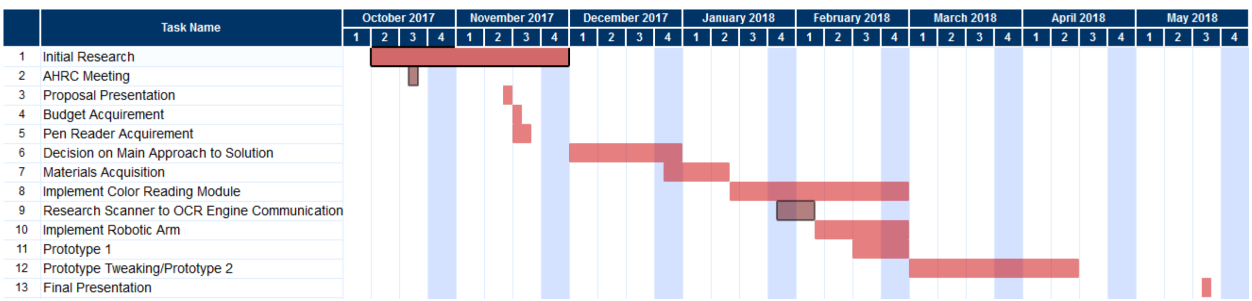
Ellis Zhu (Software engineer)- he has had a lot of internship experience which has prepared him for this project. He is a great programmer, very good with Python and excellent at programming with a Raspberry Pi. He has prior knowledge in modifying existing codes from OpenCV and writing a code from scratch and is willing to do more research.

Oluwadarasimi Adeniyi (Project Manager/ Researcher)- Has previous management experience, led a 5 person team in previous school projects, worked as a general manager intern, and is also a good researcher and finds useful technical detailed information about the project. He will be responsible for gathering useful documents, finding reliable sources and making sure the project is delivered on time.

6.3. Milestones and Timeline

Task	**Date**
Initial Research	10/07/17 – 12/03/17
AHRC Meeting	10/24/17 – 10/25/17
Project Proposal Presentation	11/14/17 – 11/15/17
Budget Acquirement	11/21/17 – 11/21/17
Pen Reader Acquirement	11/22/17 – 11/25/17
Decision on Main Approach to Solution	12/03/17 – 12/25/17

Materials Acquisition	12/20/17 – 1/17/17
Implement Color Reading Module	1/17/17 – 3/1/17
Research Scanner to OCR Engine Communication Method	1/25/17 – 2/3/17
Implement Robotic Arm	2/3/17 – 3/1/17
Prototype 1	2/15/17 – 3/1/17
Prototype Tweaking/Prototype 2	3/1/17 – 4/15/17
Final Report	TBA



7. Use of Standards

We plan to use the IEEE 802.15.1: WPAN / Bluetooth standard so as to send images received by the pen reader to the robot arm wirelessly. We chose it because it is used widely for wireless device-to-device communication.

8. Resources and Budget

Item	Unit Price	Units	Purpose	Link
C-Pen Reader	$250	1	This is the Pen Reader we plan on expanding.	https://www.amazon.com/C-pen-C-Pen-Reader/dp/B015OL7VNS

Raspberry Pi 3 Kit for develop-ment	$69.99	1	It would greatly expediate development if we have a Raspberry Pi dedicated solely as a development platform so that we wouldn't have to swap Pis in and out of our project to try some new code.	https://www.amazon.com/CanaKit-Raspberry-Complete-Starter-Kit/dp/B01C6Q2GSY
Raspberry Pi 3 for prototype	$35.05	2	One for the Color Reading Module and one for the Robot Arm	https://www.amazon.com/Raspberry-Pi-RASPBERRYPI3-MODB-1GB-Model-Motherboard/dp/B01CD5VC92
Raspberry Pi Camera Module	$28.31	1	This will be used to replace the original scanner sensor of the pen.	https://www.amazon.com/Raspberry-Pi-Camera-Module-Megapixel/dp/B01ER2SKFS/
Lynxmotion AL5D 4DOF Robotic Arm SSC-32U Combo Kit	$350.80	1	This is the Robot Arm hardware to be controlled by one of our Raspberry Pis.	https://www.robotshop.com/en/lynxmotion-al5df-kt-robotic-arm-flowbotics-studio.html
IC3D PLA 3D Printer Filament	$29.99	1	We would like to print an enclosure for the Color Reading Module to defend against accidental dropping and other damage.	https://www.amazon.com/IC3D-White-1-75mm-Printer-Filament/dp/B011RXNIXO
Turnigy	$14.99	2	This will power the Raspberry Pi on the Color	https://www.ama

7.4 V 1000 mAH LiPo Battery			Reading Module as well as the one on the Robot Arm	zon.com/Turnigy-1000mAh-Lipo-HobbyKing-Battery/dp/B0072AEHIC
Iusun Mini-360 DC-DC Buck Converter Step Down Module	$0.69	10	This is used to step down the voltage of the LiPo battery to a safe voltage that the Raspberry Pis can handle.	https://www.amazon.com/Iusun-Mini-360-Converter-Mini360-4-75V-23V/dp/B074SK9SSL

Elegoo HC-SR04 Ultrasonic Module Distance Sensor	$11.49	1	This will provide negative feedback to the Robot Arm while it is positioning itself to pick up an object.	https://www.amazon.com/Elegoo-HC-SR04-Ultrasonic-Distance-MEGA2560/dp/B01COSN7O6
Icstation RFP602 500g to 10kg Resistive Thin Film Pressure Sensor Force Sensing Resistor	$10.48	2	This will provide negative feedback to the Robot Arm while it is closing its gripping arm in order keep the arm from crushing the object. It will also sense when the object encounters resistance to movement, signifying that the place the Robot Arm is trying to place the object in is occupied.	https://www.amazon.com/Icstation-RFP602-Resistive-Film-Sensor/dp/B06ZYJRN8M
Bluetooth 4.0 USB Module	$11.95	2	This will be used so the Color Module and the Robot Arm Control Software can communicate with each other.	https://www.amazon.com/Bluetooth-802-15-1-Modules-Dongle-single/dp/B00HKILG1W
Fluke 113 True-RMS Utility Multimeter	$97.49	1	Multimeter for testing various parts and ensuring the buck converters are set up correctly.	https://www.amazon.com/Fluke-113-True-RMS-Utility-Multimeter/dp/B01EWFE6XK

Total: $989.91

Note: We have $1000 of funding from AHRC already approved.

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Appendix

Given function $f(x, y)$

Gradient vector $$\nabla f(x, y) = \begin{bmatrix} \dfrac{\partial f(x, y)}{\partial x} \\ \dfrac{\partial f(x, y)}{\partial y} \end{bmatrix} = \begin{bmatrix} f_x \\ f_y \end{bmatrix}$$

Gradient magnitude $$\left|\nabla f(x, y)\right| = \sqrt{f_x^2 + f_y^2}$$

Gradient direction $$\theta = \tan^{-1} \frac{f_x}{f_y}$$

$$\frac{\partial f}{\partial x}[x, y] \approx F[x + 1, y] - F[x, y]$$

$$\text{similarity} = \cos(\theta) = \frac{\mathbf{A} \cdot \mathbf{B}}{\|\mathbf{A}\|_2 \|\mathbf{B}\|_2} = \frac{\sum\limits_{i=1}^{n} A_i B_i}{\sqrt{\sum\limits_{i=1}^{n} A_i^2} \sqrt{\sum\limits_{i=1}^{n} B_i^2}}$$