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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED

Portable Reading Assistant Headset for the Visually Impaired (PRAHVI)

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF

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by

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Submitted in partial fulfillment of the requirements
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Bachelor of Science in Computer Science and Engineering
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ABSTRACT

Most products in the domain of assisting people with visual disabilities interpret text focus on the direct translation or dictation of text that is in front of a user. The focus is seldom on any type of textual understanding that goes beyond literal translation. In this project, we have developed the implementation of a novel wearable system that allows the visually impaired to have a better understanding of the textual world around them. Using the equivalent of a typical smartphone camera, a device captures a feed of the user's surroundings. Pre-processing algorithms for adjusting white-balance and exposure and detecting blurriness are then employed to optimize the capture. The resulting images are sent to the user's smartphone to be translated into text. Finally, the text is read aloud using an app that the user can control using touch and haptic feedback. The back-end of this system continuously learns from these captures over time to provide more significant and natural feedback based on a user's semantic queries regarding the text before them. This document includes the requirements, design, use cases, risk tables, workflow and the architecture for the device we developed.

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Chapter 1

Introduction

1.1 Motivation

Communication is the hallmark of our interactions as humans, occurring across different media, platforms, and entire paradigms. Much of the information we consume on a daily basis is provided by very specialized media, such as a newspaper or a billboard, that caters to only one specific sense, such as vision. This presents a particular challenge for individuals with sensory disabilities. Every day people absorb visual, sonic, and touch information from their surroundings. The visually impaired rely on a heightened sense of sound and touch to obtain information and are hindered from being able to easily obtain data from visual texts, such as posters, newspaper, fliers, etc. This hindrance not only affects their ability to obtain important textual information, such as warning or caution signs, but it also statistically raises the likelihood of unemployment.

1.2 Current Solutions

The Braille alphabet has been one of the most common aids in bridging the gap between textual information for people with visual disabilities. However, Braille presents significant issues around its usability, portability, and adoption. In terms of usability, Braille depends on text being translated and presented on a medium that the user can touch. This assumes the user has some indication of where the text is located, for example, on a sign. Although Braille reading systems exist, these systems are typically very bulky and must be tethered to a personal computer to operate, hindering portability. Most importantly, Braille suffers from a low literacy rate within the visually impaired community because it requires teachers with specialized training, a luxury that is not always available at public schools in the

U.S.

There are many products on the market that serve as an alternative to Braille. One example is the FingerReader by the MIT Media Lab, an electronic device that dictates the text the user touches in a document. However it can only read 12-point font that the user can physically touch. Another example, the OrCam MyEye, is a dedicated wearable headset that also performs live text dictation and can is marketed as having the capability to read text within the user's reach. However, it is priced at $2,500 which is outside the price range of many users in this segment. More significantly, its gestural input requires that the user has some visual capability to find the text. Although the FingerReader and OrCam products make significant strides toward usability and effectiveness, they still fall short of being truly practical for most users.

1.3 New Solution

There is a general issues we identified with all the current solutions involve the total cost, usability, and practicality of the system. With this system we seek to address the shortcomings of each, while incorporating their advantages. We have designed an assistive Optical Character Recognition (OCR) system consisting of a portable headset that captures a feed of the user's surroundings, a front-end mobile application that performs live OCR of the text within this feed, and a back-end framework for building a model of textual understanding. This system is capable of reading aloud the key points of the text the user is positioned to gaze at and allow the user to manipulate the translation in real-time. As with OrCam, we chose a headset form-factor to serve as the basis for capturing the user's surroundings so that the system's input follows the user's head movement in a natural, unobstructive manner. By using computer vision, we allow the user to focus on text both close as a handheld newspaper and as far as a billboard. With a mobile phone for processing, rather than dedicated hardware, we address another key shortcoming of the current solutions by keeping the cost of the device down and allowing the system to build a model for better dictation in the future. With this system, we hope to address one of the biggest daily challenges of individuals who are visually impaired, a very underserved segment of our society.

Chapter 2

Requirements

The Requirements section presents a categorized and itemized list of project requirements. Categories include Functional and Non-functional Requirements and Design Constraints. Functional requirements define what must be done, while non-functional requirements define the manner in which the functional requirements need to be achieved. Both categories have sub-categories, determined by the importance of a given requirement. Design Constraints are similar to non-functional requirements but constrain the solution and not the problem.

2.1 Functional Requirements:

- Critical
  - This system must have a visual sensor to detect text in users field of view. This ensures the device is able to recognize the text the user needs translated.
  - This system must communicate with the user through haptic feedback and voice dictation. To be usable for individuals with visual disabilities, this device must use forms of feedback and interaction that do not involve sight.
- Recommended
  - This system will have a learning model to tag specific instances of text and symbols. This allows the system to sustainably and effectively improve its overall text and symbol recognition over time.
- Specifications

- This system must process its image to text translation in a duration of 10 seconds or less.
- This system be able to recognize text on a 8.5"x11" page within a field of view of 90 degrees from 2 feet away.
- This system must be able to recognize font sizes of 10pt to 50pt within the parameters specified above.
- This system must be able to translate images to text with a word-accuracy of 80
- This system must be able to translate structured paragraph style text articles without tabular text or images.

2.2 Non-functional Requirements:

- Critical
  - This system must be easy and intuitive to recognize text in the user's environment and dictate it to the user. The target user should be able to use the system with minimal technical knowledge and/or training to ensure its effectiveness.
  - This system must be compliant with the Federal Communications Commission guidelines on wearable devices[1]
  - This system must be affordable for users, around or less than $100.
- Recommended
  - This system must be maintainable for future usage and/or upgrades. This means that the system's range of capabilities can be expanded upon in the future.
  - This system must be aesthetically unobtrusive for public consumption. As a device meant to help users more easily integrate into their social contexts, this device should provide the aforementioned capabilities without drawing unwarranted public attention to the user.
  - This system must be lightweight and minimal, less than 36 grams and no larger than the footprint of typical large sunglasses. In order to be used daily, the hardware of the device must only add minimal friction to the user's lifestyle, meaning that the device cannot have extraneous parts or weight that would hinder usage.

2.3 Design Constraints

- The main device is a wearable headset whose hardware is self-contained
- The main device's main communication with the outside world is through a smartphone
- The main device communicates primarily through sound and touch, and not through vision
- This system must be untethered from a large computing system.

[1] https://www.fcc.gov/general/ingestibles-wearables-and-embeddables

Chapter 3

Operation Modes

The Operation Modes section defines specific modes of the system, such that the system will operate differently during each mode.

Figure 3.1 shows the list of operation modes that we wanted the final product to have, but due to time constraints we only implemented the "Reading" mode.

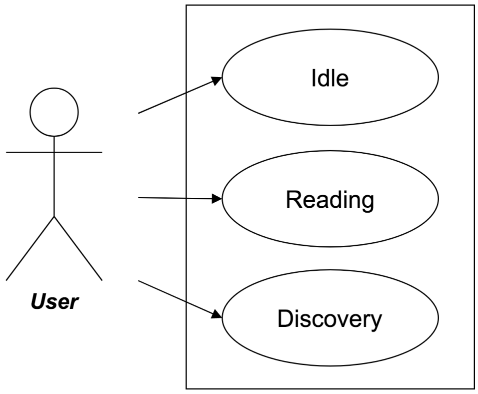


Figure 3.1: Operation Modes

Table 3.1: Operation Mode Properties

	Idle	Reading	Discovery
Goal	Put the device to sleep to preserve power	Identify and obtain large amount of text and provide feedback to user	Inform the user about potential point of interest around him or her
Actor	User		
Preconditions	Device must be turned on	Device must be turned on and set to Reading Mode	Device must be turned on and set to Discovery Mode
Steps	User set the device to idle	User stares at the document and directs the device to capture the image	User needs to move his or her head around to capture the surroundings
Postconditions	Disconnect connection to headset and server	Audio feedback send to user	Audio feedback sent to user
Exceptions	N/A	Unstable input, such that the motion of the headset is outside the threshold	

3.1 Idle

During the Idle mode, the device is put to sleep, this can be done when the user locks the smart phone. By doing so, the power supply of the device can be conserved when it is not using.

3.2 Reading

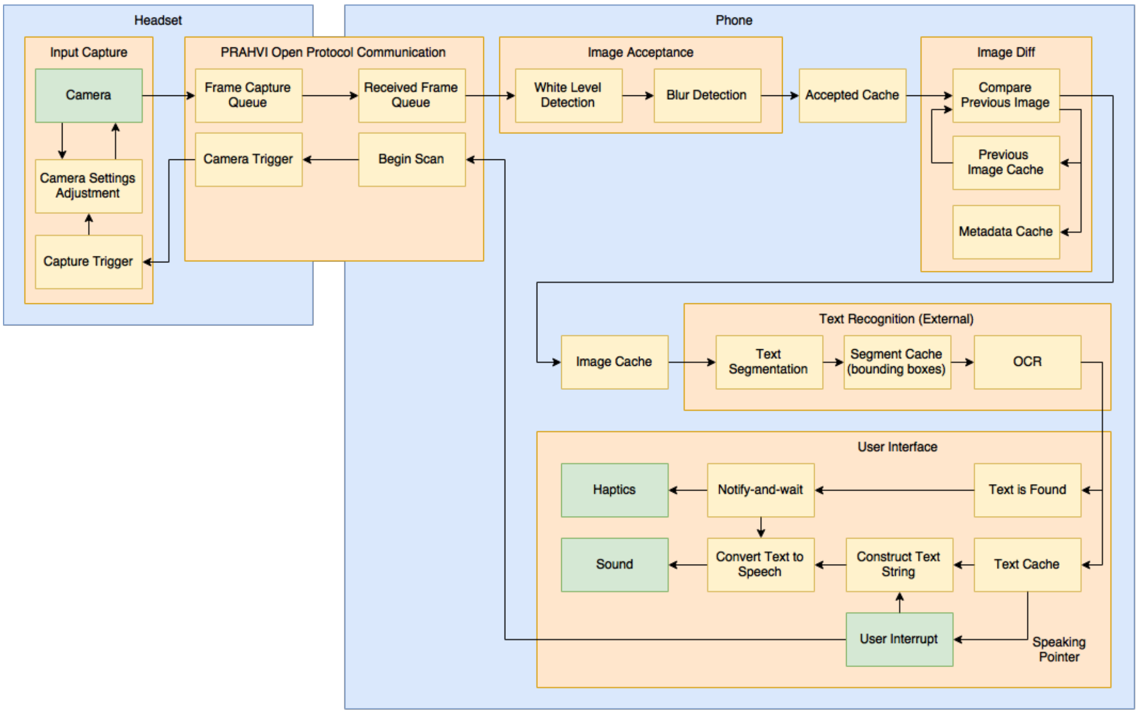
Reading mode is designed for situations where the user is sitting down or looking at a fixed location. Where the user is desire to "read" the document in front of him or her. During this mode, the device knows the user is looking at the document of interest, thus it can identify and provide the user with detailed information of the document.

3.3 Discovery

Discovery mode is intended for user to explore around the environment, it will provide the user with basic information when the device identifies them.

Chapter 4

Architecture



4.1 Activity Diagram

Figure 4.1 is the high level data-flow architecture of the system that shows the flow of actions of the user. Input is first received by the system to begin capturing an image of the user's immediate gaze, or view, in front of them. The system then evaluates the image and notifies the user if the image needs to be recaptured because it is too blurry or the text is illegible. If the image passes this evaluation, the system then translates the image into text and generates a summary for the user. This summary is

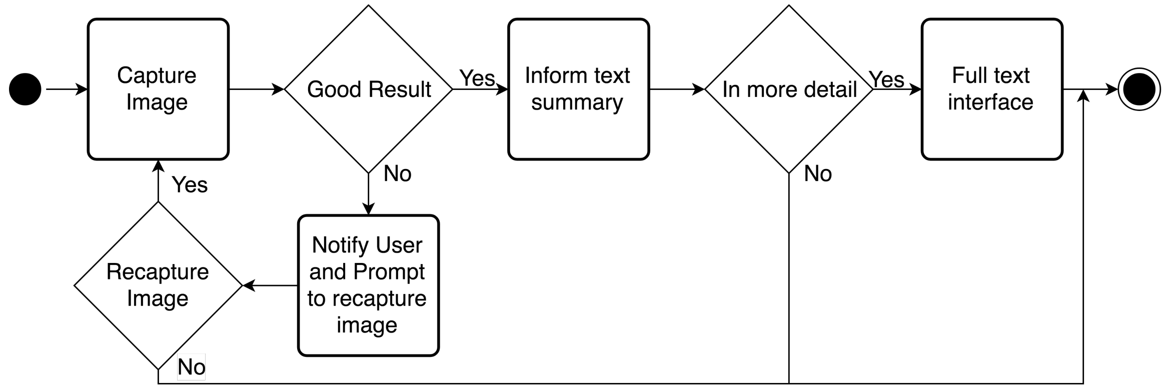


Figure 4.1: High Level View

then read aloud to the user. If the user takes no action at this point, the system proceeds to reading the entire text article. This architecture was chosen because there are constant inputs received by the system, and the inputs in general goes through the same route within the system. The data-flow architecture also has build-in concurrency, which can speeds up the process, especially the platform in which the product is embedded.

4.2 Hardware

The most visible component of PRAHVI is its wearable headset device that attaches to a typical pair of glasses or can be manufactured as a single assembly. The headset (shown in appendix 13.1) is comprised of a Raspberry Pi Zero board coupled with a standard Raspberry Pi Camera. The Raspberry Pi Zero was chosen for its low power consumption, small footprint, and its UNIX-based operating system allows for wide application flexibility. This means that the Raspberry Pi Zero allows us to cut down on the device's size and weight while creating an extensible application platform. Its main shortcoming, processor speed, is mitigated by the fact we use a smartphone and external server to process the images. The Raspberry Pi Camera is a module comprised of a breakout board and a 5.0 megapixel smartphone camera. The cable used to connect the camera to the Raspberry Pi Zero is a standard accessory cable used by many third-party accessories. Together, the Raspberry Pi Zero and the camera module can be acquired for less than $60, helping to bring the cost of a single device down for users. The modular nature of these parts allows for future expansion and easy repairs for the user and for other developers.

When the device is connected to the user's smartphone and the accompanying app is opened,

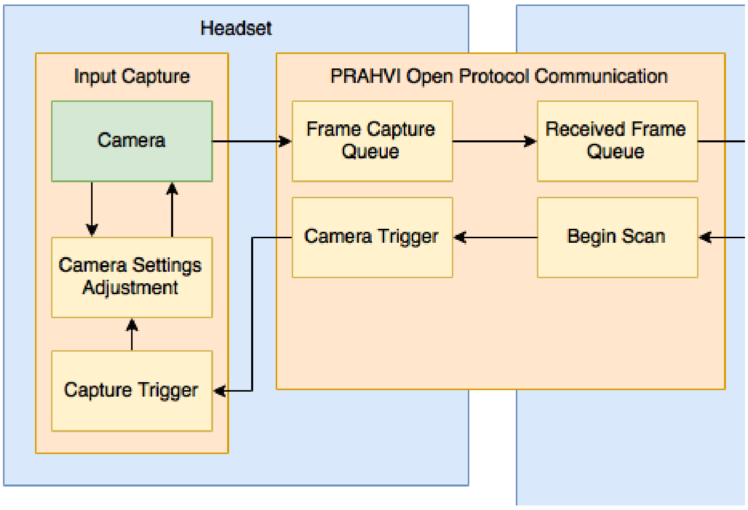


Figure 4.2: Hardware Diagram

PRAHVI powers up and immediately begins communicating with the smartphone. Once the initial setup is completed, the headset waits for a trigger from the user to begin capturing images of the user's surroundings. Once this is triggered, the camera begins capturing a set of images which are added to a frame capture queue and used to adjust the camera settings, such as white balance and exposure, to achieve an optimal capture. An image sample is then served over the bridge created using the PRAHVI Open Protocol back to the smartphone. PRAHVI Open Protocol, or "POP," is a socket-oriented connection protocol based on the open source Bonjour networking standard.[1] Although the protocol is implemented for iOS and Python for this product, the protocol can be implemented on any platform or system that supports network sockets. These technologies and systems were ultimately employed to make using PRAHVI, from the moment the user connects the device, to the point the user requests a translation, as seamless and intuitive as possible from an ergonomics standpoint.

4.3 User Interface

The user interface of PRAHVI is designed to operate entirely using haptic feedback and voice to simplify interaction and make text translation seamless. For this product, an app was written on the iOS platform to communicate with the headset device. The app (shown in 13.2) is mainly comprised of a gesture pad that spans three fourths of the entire surface of the phone screen. Once the user connects the

[1] https://developer.apple.com/bonjour/

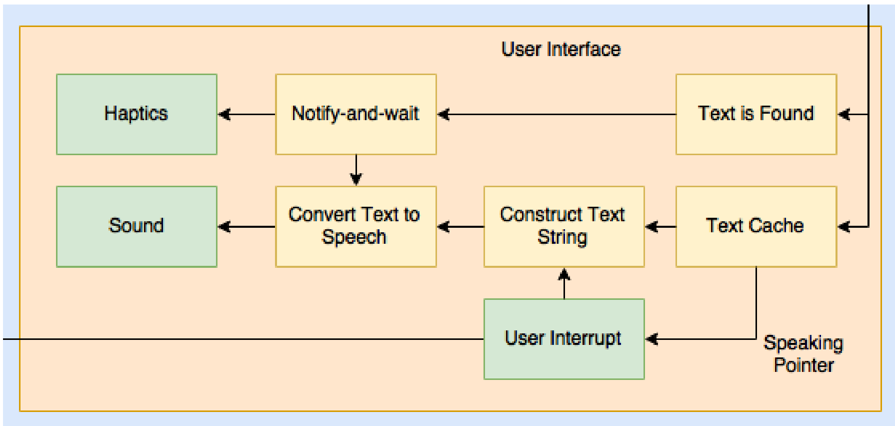


Figure 4.3: User Interface Diagram

headset and opens the app, PRAHVI immediately connects to the app to set up the POP connection. When the user double taps the gesture area, the device begins scanning the environment, adjusting the camera parameters to find a set point that produces clear, usable images. From this queue, an image is selected using image acceptance algorithms and sent to the backend for translation. Once the translation is complete, the app stores the translated text into a cache and signals to the user a quick summary (see Text Summarization section for more information) of the text before proceeding with a full translation. Swiping the gesture area allows the user to navigate the text in realtime, with the smartphone providing haptic feedback. The user primarily interacts with the app to begin translation, proceed from the summary to the full translation, and navigate the translation. By using sound and touch as the primary modes of communication for the user interface, much of the interface could actually be removed, simplifying the experience for users.

4.4 Backend

The backend of PRAHVI is a flask web application. It exposes all the functionality related to the computer vision, optical character recognition, and text summary into a an easy web interface for our iPhone application to use.

The interface of the backend is a simple set of HTTP endpoints which are summarized as follows:

- Originally, all of the functionality listed above was implemented within the iPhone application, however due to the limited compute resources of the iPhone, PRAHVI's requirements were not

Table 4.1: PRAHVI API Endpoints

Endpoint	Input	Output	HTTP METHOD	Description
/api/v1/image/ocr3	File: Image	JSON: { result: string }	POST	PRAHVI's image to text algorithm using tesseract 3
/api/v1/image/ocr4	File: Image	JSON: { result: string }	POST	PRAHVI's image to text algorithm using tesseract 4
/api/v1/text/tfidf	String	JSON: {result: { term: score, ... } }	POST	Takes in a document string and outputs the scores of all the terms in the document
/api/v1/text/compare	JSON: { text1: string, text2: string }	JSON: { result: int[0, 1] }	POST	Returns a score of how similar the documents are

being met. Image to text translation on average would take half a min, and the iPhone architecture was mangling some of the text results. For these reasons, these functionalities have been moved the backend end hosted on a server allows for a faster processing time as noted in our test bench. The server is a linux machine running an Intel(R) Core(TM) i7-4900MQ CPU @ 2.80GHz multi-core processor.

4.5 System Flow

Once the camera captures the image and sends the image to the smart phone, the image will pass through the pre-processing stage to detect whether the image will be processed or not, based on the blurriness of the image and the similarity of the current image and the previous image (see Image Pre-processing for more information). Once the image has passed the pre-processing stage, it is also processed for text, which is stored in the smart phone. Access to text is by string, and different lines are separated by the new line character that is the same as the document captured. The text is then output as audio feedback as decided by the user.

$$C(i,j) = \sum_{m=0}^{(Ma-1)} \sum_{n=0}^{(Na-1)} A(m,n) * B(i-m, j-n)$$

Figure 4.4: 2-D Convolution Equation

4.6 Text Extraction

4.6.1 Image Pre-processing

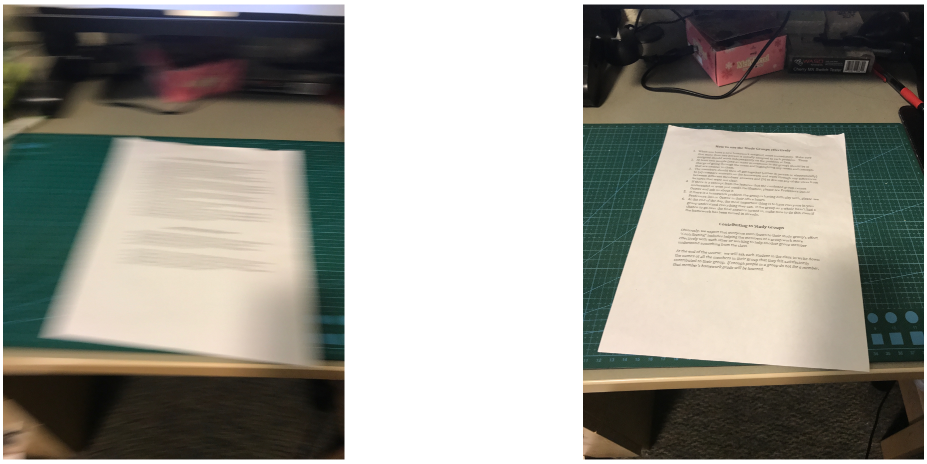
When the smart phone application receives the image, the image is passed through two filters. The first filter detects the blurriness of the image as described below. If the image is blurred, which is determined by the smart phone application, it will be rejected because it is hard to extract useful information from a blurred imaged. If the image passes the blurriness test, it will then be compared to the previous detected image for similarity. If the image is similar (or the same), as determined by the smart phone application, the image will also be rejected, because the information from the same document is stored in the device from the previous capture. These 2 filters help to improve the efficiency of the system and save time waited by the user.

Blurriness Test

To test for blurriness, variance of Laplacian [1] is used. The image is treated as a 2-dimensional matrix (after grayscaled), and convolve (see Figure 4.4) it with the 3x3 Laplacian kernel (see Figure 4.6). The variance of Laplacian is the variance of the response. The variance of Laplacian of the image is then compared to a threshold value (the threshold value used for this system is 50). If the variance of Laplacian of the image is lower than the threshold, then the image is blurred, otherwise, it is not.

Similarity Test

The similarity test uses the accelerated-KAZE (AKAZE) local features matching [2]. The AKAZE local features matching returns a list of matches between the two images. We consider the two image is similar if the number of good matches is above the threshold (the threshold value used for this system is 1000), then the images is said to be similar. In other words, if the two images have the numbers of good matches that is greater than the threshold value, it is said to be similar.



(a) Blurred image (b) Not blurred image

Figure 4.5: Blurred image & not blurred image

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Figure 4.6: The Laplacian kernel

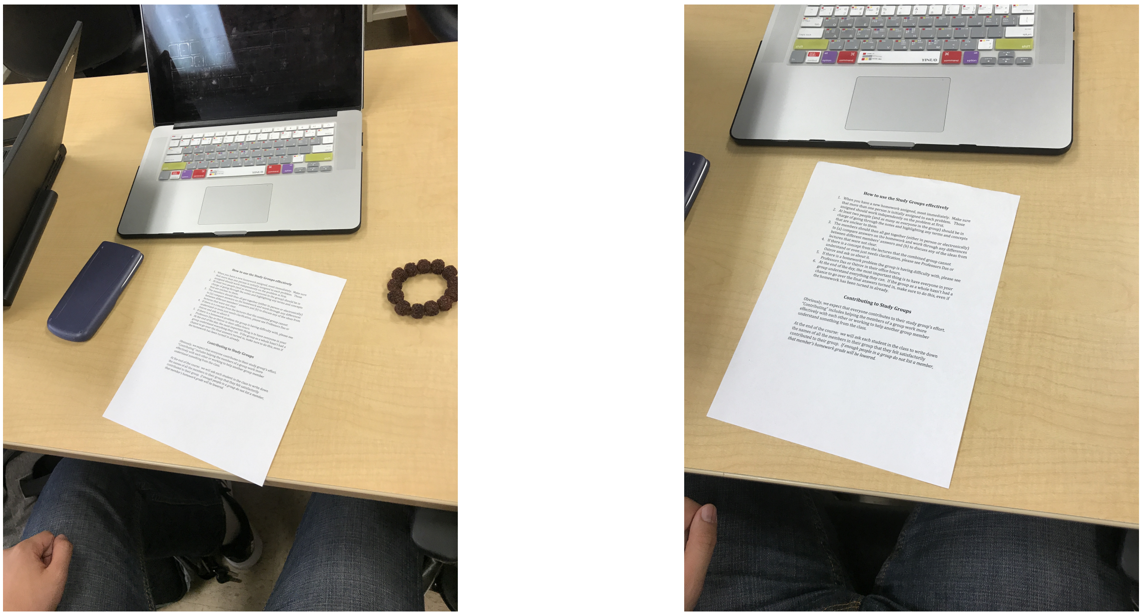


Figure 4.7: Similar Images

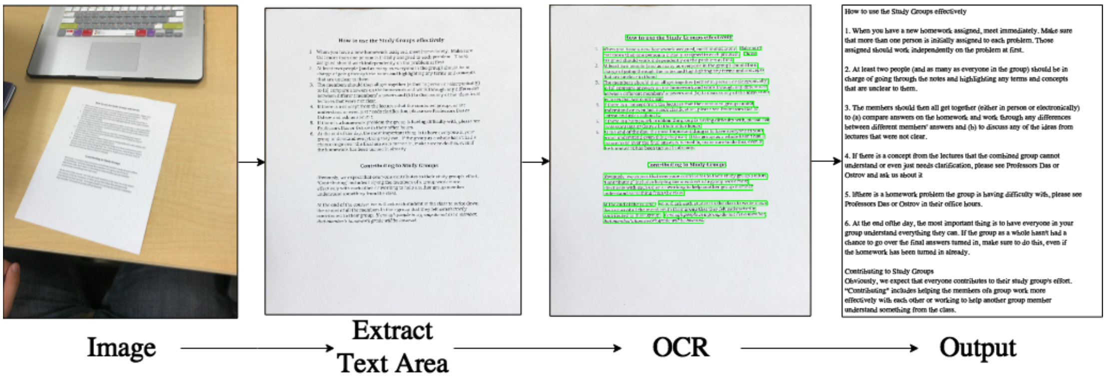


Figure 4.8: Image Process Flow

$$G_0(x, y) = Ae^{\frac{-(x-\mu_x)^2}{2\sigma_x^2} + \frac{-(y-\mu_y)^2}{2\sigma_y^2}}$$

Figure 4.9: Gaussian Blur Equation

4.6.2 Image Processing

When the image has passed the blurriness test and the similarity test, the system will try to detect the text area in the image and extract the text area as described below. The extracted text area is then sent to the Tesseract Optical Character Recognition (OCR) Engine to convert the image to computer encoded characters. (see Figure 4.8)

Text Area Extraction

To extract the text area, a copy of the image is first blurred (5x5 Gaussian Blur is used in implementation [3]) to reduce noise. Then detect the edges in the image (Canny Edge Detection is used in implementation [4] with threshold [0, 50]). The Canny edge detection has a low error rate, good localization and minimal response for the edges.

Canny edge detection first filter out any noise, then find the intensity gradient of the image, apply non-maximum suppression, lastly hysteresis using the two thresholds.

From the edges of the image, contours are then collected [5] from the connected edges and sorted in descending order based on their area.

From the list of sorted contours, the biggest contour that can be approximated by a quadrilateral is identified as the text area. The text area is applied to a perspective transformation to convert the text area to a rectangle to create uniform sized characters (See Figure 4.8-Extract Text Area). This increases the accuracy of the result from Tesseract OCR Engine.

Text Detection

The transformed text area is processed by the Tesseract OCR Engine to identify the bounding boxes (See Figure 4.8-OCR) of the text in the image and convert the image to computer encoded characters. The computer-encoded characters are then processed to extract key features and feedback to the user. (See appendix for the original and detected sample testing documents.)

4.7 Text Summarization

In order to provide users with a summary of the extracted text we use an algorithm called Term Frequency-Inverse Document Frequency [6] (TFIDF). The reason why TFIDF was chosen for our text summary is because it's one of the more popular and well known term-weighting schemes, it's easy to implement, and once it's set up it is computationally fast.

The goals of TFIDF are to obtain statistically important keywords from a text article.

It does this by giving each word in the target document a score based on two statistics, the word frequency and the inverse document frequency.

The word frequency is simply the number of times the word appears in the target document and the inverse document frequency is calculated by taking the log of the total number of documents in a text corpus (described below) divided by the number of documents that the word appears in.

The final score for each word is calculated as follows:

$tf(t,d) * idf(t,D)$

where,

$tf(t,d) = 1$ if term t is in Document d else it's 0

$idf(t,D) = log(\frac{N}{|d \in D : t \in d|}$

where,

N is the number of documents in the corpus $N = |D|$

$|d \in D : t \in d|$: number of documents where the term t appears.

The rationale behind the TFIDF algorithm is to reduce the importance of words that appear often yet have no overall significance. Examples of such words are: the, and, is, etc.

The corpus of documents are gathered in the news domain so that our text summarization is inline with the domain of PRAHVI functional requirements. Our strategy was to build our corpus by scraping the top online news repositories for all of there news articles.

We took the 50 top online news websites. We used a Python library called Newspaper to gather the content of every article currently exists on the site.

Once our corpus was collected we precomputed the inverse document frequencies for each term in our corpus.

Chapter 5

Design Rationale

5.1 Architecture

- Hardware
  - Wired Headset Device Form Factor
    * Although many consumer electronics are moving to wireless form factors, the wired headset form factor was chosen to deliver a better experience that fits this unique set of users' needs. In particular, we focused on the areas of latency and usability. The wearable form factor was chosen because it best fit the use cases that users are presented with when translating text. This means that the headset is readily available and in-position for the user to translate text upon request. Utilizing a wired form factor ensures that there is no latency or ambiguity in setting up the connection and communicating from the device to the smartphone. A wired form-factor also potentially eliminates the need for the user to maintain knowledge of a secondary battery or configure their device to pair with the smartphone.
  - Haptic and Audible User interface
    * The smartphone application that accompanies the device communicates with the user entirely through haptic and audible feedback. The user interface is deliberately "stripped-down" to its singular component, the gesture area. The user double-taps to begin the translation process, single-taps to pause or start a dictation, and swipe to navigate. This product must appeal to people with a sliding scale of blindness, some with vary-

ing conditions that warrant a user interface that can appeal to the lowest common denominator.

- Software
  - Image preprocessing before Optical Character Recognition
    * The current Tesseract OCR Engine operates poorly with images that contain skewed text or visual artifacts. To improve on the overall accuracy of the system, preprocessing is employed to detect blur and visual artifacts while deskewing the image as best as possible to improve performance of the OCR engine.

5.2 Technologies Used

- Tesseract Optical Character Recognition Engine version 4 An open source OCR engine licensed under Apache License, Version 2.0.[1] It is one of the most accurate open source OCR engines currently available.
  - Currently, the most accurate open source solution to optical character recognition
  - Using state of the art machine learning models for word recognition
  - Highly documented with academic papers written about its architecture
  - Constantly being developed by a community of developers, so if we run into problems we have a community to ask questions to
  - Has both a C (python wrapper) and a C++ API
  - Supported by Google
- OpenCV An open source library of programming functions mainly aimed at real-time computer vision. Licensed under BSD license.[2]
  - De Facto standard software libraries for computer vision
  - Lots of developer support
  - Open source
  - All of its data structures are compatible with Tesseract's API
- Flask Flask is a lightweight Python web framework upon which PRAHVI's backend is built.
  - Web client framework with the smallest learning curve
  - Fast and intuitive web API development
  - Open Source
- Nginx Nginx is a proxy server technology used to deploy our Flask web server and expose it via the internet.

[1] https://www.apache.org/licenses/LICENSE-2.0.txt
[2] https://en.wikipedia.org/wiki/BSD_licenses

– Allows us to deploy our Flask application onto the web

– Seamless integration with Flask

– Open Source

Chapter 6

Testing

The following describes how the product is tested.

6.1 Alpha Testing

6.1.1 Function Testing

During function testing, each part of the system was tested individually. The following are some examples of function testing performed:

- Graphical input from camera
- Corresponding OCR input and output
- Summary feedback to user

6.1.2 System Testing

The system was tested as a whole. The test is focused on where all modules and functions within the system are cooperating with each other, and whether the system functions as a whole.

Performance

The performance of the system is tested with a test set of 30 images (see Figure 6.1) with both versions of Tesseract OCR Tesseract 3.05.00 [7] and Tesseract 4.00.00 [8].

The test results (see Table 6.1) show that Tesseract 4 provides significant better results than Tesseract 3, even though Tesseract 4 is still in alpha stage.

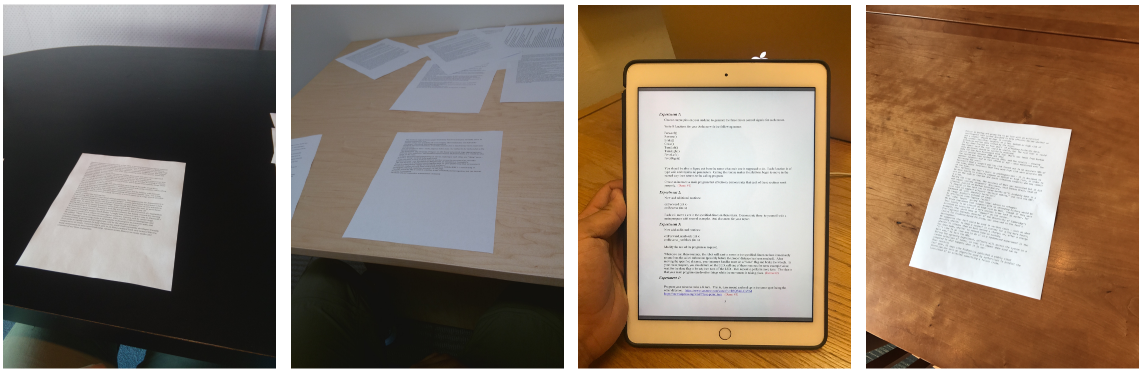


Figure 6.1: Testing images gathered during System Testing

Table 6.1: Performance Analysis

	Accuracy (%)		Response Time (Sec)	
	Mean	Standard Deviation	Mean	Standard Deviation
Tesseract 3	35.93	21.37	11.05	4.68
Tesseract 4	91.07	7.24	3.07	0.60

The documents in the test images are collected from BBC News (www.bbc.com). This way the ground truth of the document (the original computer encoded characters) can be used to compare with the result of the system.

The test images cover a variety of different backgrounds, motions, blurriness and brightness.

Chapter 7

Development & Manufacture Costs

7.1 Development Cost

Table 7.1 shows the list of items we have purchased in order to complete this project. The main cost during the development stage is the smartphone device, followed by the adapter and cables, and the circuit board.

Table 7.1: Development Cost

Item	**Cost**
Circuit board	\$50.00
Smartphone	\$500.00
Adapter and Cables	62.98
Google Cardboard	\$25.00
Battery	\$21.00
10% Tax	\$65.90
Total	**\$724.88**

Table 7.2: Per-Unit Material Cost (Projected)

Item	**Estimated Cost**
Computing Module	$15.00
Device Housing	$3.00
Smartphone Device	Already owned
Adaptor and Cables	$40.00
Total	**$58.00**

7.2 Manufacture Cost

Table 7.2 shows the projected per-unit material cost. As mentioned before, the cost of manufacture the headset is greatly reduced compared to similar products in the market.

Chapter 8

Risk Analysis

The Risk Analysis table defines a potential set of risks that our group could face, resulting in setbacks to timely progression towards our finished project. For each risk, there are two potential consequences, a probability value ($0 \rightarrow 1$), a severity value ($0 \rightarrow 10$), an impact value (impact=probability*severity), and two potential mitigation strategies. The risks are ordered from greatest to least impact value (top-to-bottom).

Table 8.1: Risk Table

Risk	Consequences	Probability	Severity	Impact	Mitigation Strategies
Software platforms or hardware are difficult to link together	Development blocked	0.5	9	4.5	Use common, open-source platforms that have supports. Modulize the system, such that every part can be replaced easily. Communicate effectively with team members.
Low content accuracy	System becomes less accurate	0.4	8	3.2	Make good use of user interaction such that the device may instruct the user to reposition to getter better results and rely on the expertise of advisors
Long response turnaround time	Long wait time for the user	0.4	7	2.8	Implement the system such that it is able to transfer to faster framework or more powerful hardware
Too hard to get good environment with light	Unable to get performance data Result is less accurate	0.5	3	1.5	Use camera than can change the focus, exposure and white balance when capturing the image
Too narrow a range of operability	System becomes less useful	0.3	4	1.2	Implement the system that is able to operate and cover most situations

Chapter 9

Development Timeline

The Development Timeline presents a general outline, in Gantt chart form, of when various project steps will be completed and by which project member(s). Steps are divided into three sections: Requirements, Design, and Implementation. A legend provides a reference for the utilized color-coding.

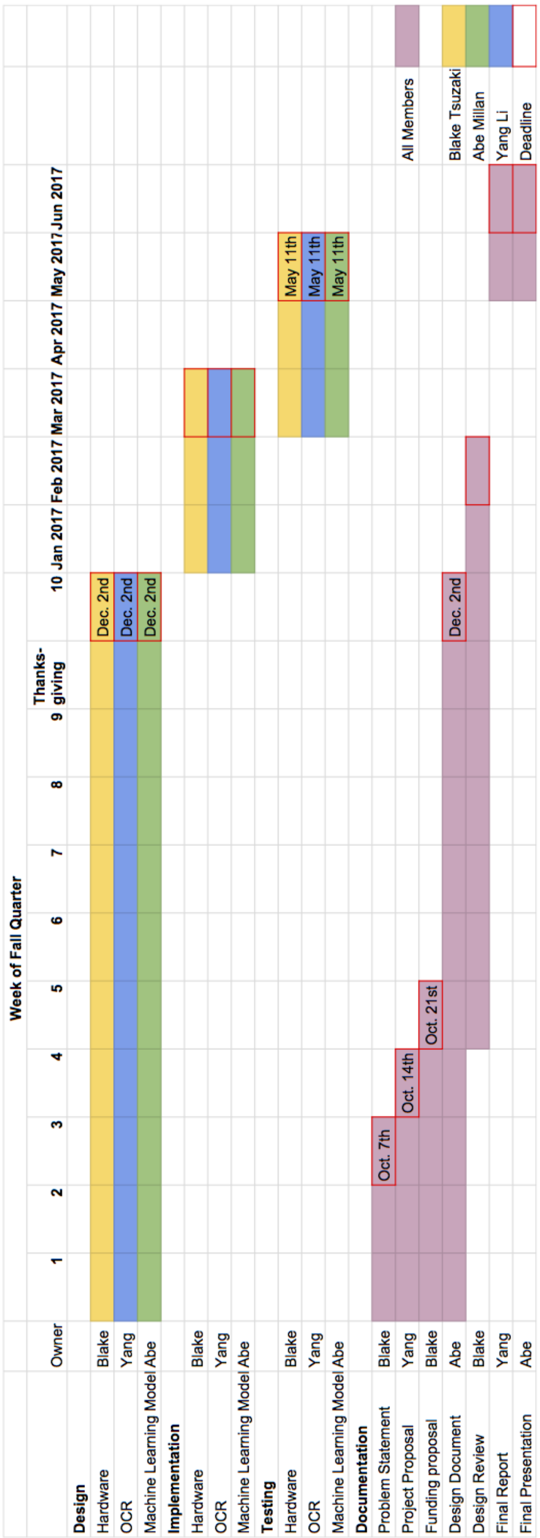


Figure 9.1: Development Timeline

Chapter 10

Ethical Analysis

The primary goal of PRAHVI is to help individuals with visual disabilities more easily integrate into society. With millions of Americans living with some level of blindness, there was an opportunity to significantly affect a broad set of individuals with some very specific challenges. Working with the university's disabilities office, we discovered typical use cases involving navigating one's indoor environment, identifying and reading texts that have no digital equivalent, and independently interacting with one's outdoor environment. These simple tasks help individuals become more productive, opening broad opportunities for work and fuller lives. Improving any single one of these daily tasks vastly improves the quality of life for individuals in this segment.

Through our ethical analysis we discovered that one of the most important attributes successful engineers have is the ability and willingness to observe their work in the broad scope of the people they affect. Although the requirements, design, and implementation of PRAHVI changed during the course of its development, the team was constantly guided by the factors that would deliver the best experience to our target users given the time and resources we have. Most notably, this included prioritizing features with a sense of those that could be completed in a reasonable timeframe while driving our primary objective. This mindset ensured the success of the project in the face of unexpected developments by focusing on the desires of the stakeholders involved.

Although PRAHVI is classified as an assistive device, its usage comes with ethical implications of its operation that we took into account during the development process. The main ethical implications are ultimately predicated on the newfound independence users gain by using PRAHVI, at the potential expense of privacy or inaccurate translation. In terms of privacy, a simple case could arise when PRAHVI is used to translate sensitive information such as a bank statement or an address. As PRAHVI dictates the text it reads, the translation could be accidentally read to bystanders as well as the user. A more complex case could involve a malicious actor gaining unauthorized access to the device, by way of "hacking" it, and in turn record the sight and whereabouts of the device during usage. Such information could compromise the user's sensitive information or place him or her at risk of other attacks such as fraud or assault. These factors were taken into account during the development of PRAHVI and its software architecture to ensure that the risk for stakeholders is minimized.

Chapter 11

Sustainability

Sustainability is an essential factor in delivering a product that will benefit people's lives and create value. During the design of PRAHVI, we have identified multiple points of sustainability through the lifecycle of the product: from its environmental costs, to its user interaction, to its economic viability. By evaluating these facets, we can draw a concrete triple bottom line to evaluate the effectiveness of the product in the context of an actual business model.

As a product, PRAHVI is designed primarily using off-the-shelf components that have been developed at scale both to reduce costs and to minimize its environmental footprint. Its construction consists mainly of a PCB board, a camera module, a plastic enclosure, and a cable to connect the product to the user's smartphone. The board used in the current version is the Raspberry Pi Zero, a lightweight, low-power board designed for mobile applications. This means that PRAHVI operates using less than 100mW and can be powered entirely by a smartphone's accessory port. The electrical components are manufactured in compliance with the global Restriction of the Use of certain Hazardous Substances (RoHS) regulation. Additionally, each company we have sourced components from have publicly pledged their products to be free of conflict materials and use minimal amounts of rare-earth metals. This allows us to minimize the environmental impact of both construction and disposal of the product by accounting for its individual materials and by following federal and international procedures. The enclosure is constructed using a 3D printer with ABS plastic material. Although this material is not biodegradable, using a pure ABS filament and designing the product to be modular allows a recycling entity to separate the components and recycle the ABS plastic. Overall, we anticipate a single PRAHVI unit to last the life cycle of the user's smartphone, typically 2-3 years. This accounts for future feature upgrades and the general durability of the product against normal wear and tear. By accounting for each of these factors during the design phase of our project, we can minimize PRAHVI's overall environmental footprint.

In terms of social sustainability, we have chosen a very clear demographic that has been largely untapped for innovation. Making PRAHVI a promising product for this field. PRAHVI is designed to assist users with visual disabilities navigate their visually-oriented environments, from casual reading to discovering signs and posters. The use cases it presents are context-specific but very familiar to those who struggle with these tasks on a daily basis. Because we tailored the interface of the product to individuals with partial or full visual disability, making the product intuitive presents a unique challenge for us. By crafting an interface that communicates primarily through sound and haptic feedback, we believe that the product is intuitive and useful for the user. Furthermore, test the product through usage exercises and potentially real-world user tests. However, creating a product for this niche also introduces the possibility that users will develop an implicit dependence on the product. Should the user begin entering high-risk environments on his or her own, such as navigating a busy street, the stakes for failure could mean the difference between life or death. Therefore, for the first few iterations of the product, we would advise users only to use the product in a controlled environment with minimal hazards and many safeguards. Overall, we hope that PRAHVI can add significant value to a user's daily life with the objectives we have set, using the technologies and sense of interface we have developed.

The final metric for a product's viability involves economic sustainability, particularly in a world saturated with electronic assistance devices. By utilizing off-the-shelf components and relying on a smartphone that users in this demographic typically already have, we have made strides in minimizing the cost of the product to well below current solutions. Our target cost of the product was less than \$200, which is a fraction of the closest competing product, OrCam, which is priced at \$2500. Much of the cost for such devices is in the software and the processing unit, as these devices are typically designed to be standalone. During the design phase of our project, we studied the demographic of individuals with visual disabilities and found that many typically own and use a smartphone on a daily basis. This means that we can safely trade off a small measure of convenience with a standalone device for the cost savings of using a processing unit users already own. Additionally, this drives down the cost and frequency of future upgrades, as the device's processing power is upgraded for free with every new smartphone a user purchases. This means less revenue is spent on developing and manufacturing new

PRAHVI processing modules.

Most of PRAHVI's revenue would go to the material cost of the components and development and testing of the software. Additionally, the retail cost to the end user can typically be augmented by support from their insurance providers. In the future, PRAHVI may be manufactured entirely using a custom PCB board and custom hardware that, at scale, would further drive down costs while delivering a more integrated product. From an economic standpoint, PRAHVI is an effective product in this segment, especially compared to competing products, by using a careful mix of tradeoffs that overall benefit users.

We hope that PRAHVI meets or exceeds the triple bottom line to remain a fully-sustainable product. By identifying a key niche ripe for innovation, then sourcing parts and development in an environmentally and economically responsible way, we envision a life cycle that helps the product remain viable for many iterations. With each iteration, we also hope that the product can incorporate fixes and improvements that make it more useful for users and even expand its target audience. These goals overall would help create the framework for a transition from a simple design project into an actual product.

In a world with increasingly limited natural resources and a larger focus on industrial impact on our environment, sustainability is a significant part of research and development. During the design of PRAHVI, we have identified processes, components, and the sourcing of these components to evaluate its environmental impact. As a product that spans multiple industries, we recognize that PRAHVI's lifecycle includes many stakeholders and resources, from manufacture, to daily usage, to final disposal.

The construction of PRAHVI begins with its components, their sourcing, and overall assembly. The primary component of the device is its printed circuit board (PCB). For research purposes, we have used an off-the-shelf board known as the Raspberry Pi Zero. This board consists of plastic for the board itself, laser-etched copper traces, and components with varying amounts of copper, silicon, and gold. In compliance with the global Restriction of the Use of Certain Hazardous Substances (RoHS) regulation, the Raspberry Pi is manufactured without the use of conflict materials and minimal use of rare-earth elements. In addition, the camera module by Sony Inc. is manufactured under stricter regulations that replace many materials, such as those that go into the imaging sensor, with more environmentally-friendly, albeit slightly more expensive alternatives. We found that the small form factor of the Raspberry Pi not only makes the product more portable, but uses fewer materials, while still meeting our quality and performance requirements. Although other boards and modules were evaluated, most are manufactured under small-scale operations that use more resources or did not meet our requirements. The case of the product is manufactured using a 3D printer with ABS plastic material. This material is not biodegradable, and must be recycled at the end of the product's lifecycle. During the design phase of this project, we selected what we believe are the optimal components and materials for PRAHVI from a performance and environmental standpoint.

As a holistic product, PRAHVI introduces challenges to managing energy consumption from manufacture, to delivery, and daily use. The parts used in PRAHVI are sourced primarily from China. With careful design and planning, we consolidated our parts orders into three stages and from a single supplier to ensure that we minimized the impact of transportation in the product. The case, which is manufactured using a MakerBot Replicator 2X, is the only part we manufacture ourselves. For research purposes, using a 3D printer significantly reduces the energy and resource overhead of a professional manufacturer, while providing a representative component of the final product. During use, we anticipate that PRAHVI will be powered entirely using a smartphone device, removing the need for a separate battery. Its small form-factor and ARM processor allows PRAHVI to operate with minimal power use. We increase these energy savings by defining clear contexts in which PRAHVI is in a passive sleep mode and when it is in an active scanning mode. These practices combined help to minimize the overall energy footprint of PRAHVI as a product.

Finally, although PRAHVI is designed with longevity of the product in-mind, we incorporated its end-of-life into the design process. PRAHVI is made with standard components, each of which can be easily replaced. We anticipate that PRAHVI can be used throughout the standard lifecycle of a smartphone, around two years. This accounts for component failures, the likelihood of damage resulting in a system failure, and required feature upgrades for new versions of the smartphone's software. At the end of the device's lifecycle, the components of the Raspberry Pi Zero can be easily extracted and recycled through standard protocols. In addition, the case is entirely constructed from ABS plastic that can also be recycled and repurposed. These considerations help ensure that PRAHVI is built to last with the user's needs as well as transition out of use in a sustainable manner.

Chapter 12

Conclusion

In this project we designed and implemented a novel and cost-efficient device that assists individuals with visual disabilities. Our device allows users to navigate text by taking a picture of an article of text that they are gazing at, translates this image to text, and finally provide a summary of the text to the user. Through our development and optimization, we were successful at achieving an image-to-text accuracy of around 91% while keeping the turnaround time as low as 0.60 seconds under ideal network conditions and using the domain of text documents. Costs were kept low by working with general purpose computing hardware such as the Raspberry Pi Zero, and the ubiquitous smart mobile devices. However, PRAHVI still has a ways to go before it is a shippable product for customers. In the future, we would like to make our system extensible to more text domains and enable it to perform more robustly in harder lighting situations. In particular, the OCR system operates poorly in environments with too much light. We also hope to optimize the device's power consumption so that the device can be powered entirely off the smartphone without an external power source. Overall, we hope that this project will be one of many to usher in a new era of wearable devices that target this largely untapped and underserved market to improve users' lives and help them more easily integrate with society

Chapter 13

Appendix

Figure 13.1: Hardware

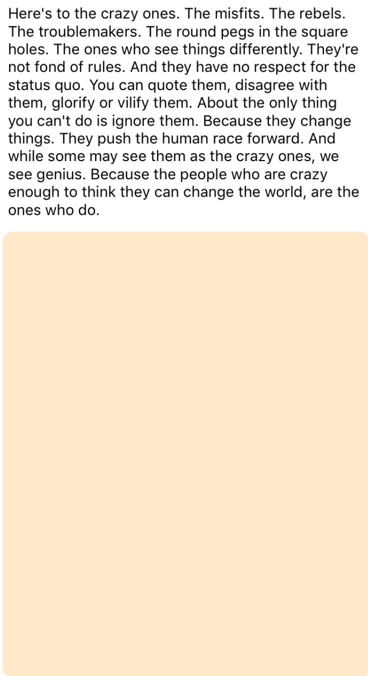


Figure 13.2: User Interface

13.1 Sample Testing Documents

13.1.1 Can Amazon's assistant stay on top?

http://www.bbc.com/news/technology-39853718

Original Text

Amazon surprised everyone when, in late 2014, it unveiled a standalone digital assistant that was not only good, but blew away the competition in both quality and aesthetics. The Echo - a cylindrical speaker with microphone - now accounts for just over 70% of all digital assistant use in the US, leaving its nearest competitor, Google Home, well behind. It's an important new market, even if the idea of talking to an object in your home still comes uneasily to many of us. In a new report, Emarketer estimated 36 million Americans will use a voice-activated assistant at last once a month - an increase of 129% on this time last year. Amazon, as I mentioned, already has the lion's share. It's now hoping to echo (sorry) that success with its latest effort which we could see as early as Tuesday, according to reports. AFTV.com, a site with a solid track record of leaks, said it found a low-quality image of the device on Amazon's own servers. The authenticity of the image was later backed up by king-of-the-leaks, Evan Blass. The new device is expected to house a 7-inch touchscreen and can be used for video calling, as well as displaying weather information and other data. It will help plug that gap that many voice assistant users will be familiar with, like not knowing how long a timer has left without asking. Or just knowing the time - it's a step backwards to not just look at a clock. Of course, a screen opens up a range of new possible interactions. 'Barely crossed the starting line' Dominating this area isn't just about selling assistants. The opportunity for Amazon here is in an arena few thought they become a major player - home automation. Emarketer's data suggests that once you opt for one brand of assistant in your home, you're very unlikely to jump ship. So when the "internet of things" boom finally hits (any day now, as we've been saying the past three years) Amazon's early lead could really start to pay off. Or, it could blow it. Consider Amazon's lead like doing well in the first event of a heptathlon. "Amazon has a head start in the voice race but the industry has barely crossed the starting line," said CCS Insight analyst Geoff Blaber. I caught him as he was on his way to Microsoft's developer's conference, where its own digital assistant, Cortana, will be centre stage. He added: "Those that can maximize customer data, search, artificial intelligence and natural language processing, make it all available to developers to innovate with, and simultaneously walk the privacy tightrope, will be the ultimate winners." As it seeks to rapidly expand its lead, Amazon has made itself incredibly developer-friendly compared to its rivals. I recently had a spin in an Alexa-enabled Ford, and General Electric today announced an Alexa-powered lamp. Amazon wants Alexa in as many nooks and crannies of our lives as possible.

Detected Text

Amazon surprised everyone when. in late 2014. it unveiled a standalone diaitat assistant that was not only good. but blew away the competition in both quality and aesthetics. The ticho - a eytindrical speaker with microphone - now accounts for just over 70%6 of all Jurital ausistant use in the US, leaving its nearest competitor, Google Home, well behind. #'s an important new market, even if the idea of talking to an object in your home still comes uneasity to many of us in a new report, Emarketer estimated 36 million Americans will use a voice-activated at last once a month - an increase of 129% on this time last year Amazon, as I mentioned. already has the lion's share, It's now hoping to echo (sorry) that with its latest effort which we could see as early as Tuesday. according to reports AIPTV.com, a site with a soild track record of leaks, said it found a low-quality image of the device on Amazon's own servers. The authenticity of the image was later backed up by king-of the- leaks. Evan "The new device is expected to house a 7-inch touchscreen and can be used for video calling. as well as displaying weather information and other data: It will help plug that wap that many voice assistant users will be familiar with. like not knowing how long a timer has left without asking. Or Just knowing the time -it's a step backwards to not just look at a clack. Of course. a screen opens up a range of new possible interactions. "tarely croused the starting tine" Dominating this area isn't just about selling assistants, The opportunity for Amazon here is in an arena few thought they became a major player - home automation. Emarketer's data sumrests that once you opt for one brand of assistant in your home. you're very unlikely to Jurnp ship. So when the "internet of things" boom finally hits (any day nowe as we've been saying the past three years) Amazon's early lead could really start to pay off. Or it could blow it. Consider Amazon's lead like doing well in the first event of a heptathlon. "Amazon has a head start in the vaice race but the industry has barely crossed the starting line." said CCS Insight analyst Geoff caught him as he was on his way to Microsoft's (developer's conference. where its own digital assistant, Cortana, will be centre stage: He added: "Those that can maximize customer data, yearch, artificial intelligence and natural language processing. make it all available to developers to innovate with. and simultancousty walk the privacy tightrope. will be the ultimate winners." As it seeks to rapidly expand its ead. Amazon has made itself incredibly developer-triendy compared to its rivals I recently had 'a spin in an Alexa-enabled Ford. and General Electric today announced an Alexa-powered lamp. Amazon wants Alexa in as many nooks and crannies of our tives as possible. t

13.1.2 Dubai becomes first city to get its own Microsoft font

http://www.bbc.com/news/business-39767990

Original Text

Not content with having the world's tallest building and biggest shopping centre, Dubai has become the first city to get its own Microsoft-designed font. The typeface comes in both Latin and Arabic script, and will be available in 23 languages. Government bodies have been told to use it in official correspondence. But given the human rights record of Dubai and the United Arab Emirates, eyebrows will be raised at claims it is a font of "self-expression". 'Create harmony' Dubai's Crown Prince Hamdan bin Mohammed al-Maktoum said he had been personally involved in "all the stages" of the development of the font. It was "a very important step for us as part of our continuous efforts to be ranked first in the digital world," he added. "We are confident that this new font and its unique specifications will prove popular among other fonts used online and in smart technologies across the world". Dubai's government said the typeface's design "reflects modernity and is inspired by the city" and "was designed to create harmony between Latin and Arabic". When self expression isn't usually your type "Self-expression is an art form," says the blurb accompanying the launch of this font. "Through it you share who you are, what you think and how you feel to the world. To do so you need a medium capable of capturing the nuances of everything you have to say. "The Dubai Font does exactly that. It is a new global medium for self-expression." But the United Arab Emirates - of which Dubai is part - has been criticised for its restrictions on free speech. The constitution does guarantee the right to freedom of opinion and expression, but Human Rights Watch (HRW) says this "has no effect on the daily life of the citizen" and the country "has seen a wave of arrests and violations of human rights and freedoms and mute the voices of dissent". In March, high-profile human rights activist Ahmed Mansoor was arrested, a move HRW said showed "complete intolerance of peaceful dissent". The UAE's official news agency, WAM, said Mr Mansoor had been held "on suspicion of using social media sites to publish "flawed information" and "false news" to "incite sectarian strife and hatred" and "harm the reputation of the state."

Detected Text

Not content with having the world i tallest building and best shopping centre, Dubai has become the first city to get its own Microsoft designed font: "The typeface comes in both Latin and Arabic script. and will be available in 23 languages. Government bodies have been told to use it in official correspondence Wat aiven the human rights record of Dubai and the United Arab Emirates. eyebrows will be raised at claim it in a font of "welt-expression". 'Create harmony Bubal's Grown Prince Hamdan bin Mohammed al- Maktoum said he had been personally involved in "all the stages" of the development of the font. It was "a very important step for us as part of our continuous efforts to be ranked first in the world he added. "We are confident that this new font and its unique specifications will prove popular among other fonts used ontine and in smart technologies across the world". Dubai's government said the typeface's destin "reflects modernity and is inspired by the vity" and "was destined to create harmony between Latin and Arabic'. When self expression isn't usually your type "Seit exnression is an art form" says the blurb accompanying the launch of this font. "Ihrough it you share who you are. what you think and how you feel to the world. To do so you need a medium capable of capturing the nuances of everything you have to say. "Ime Dubai Font does exactly that. it is a new global medium for self-expression." hat the United Arab Emirates - of which Duba is part - has been criticised for its restrictions on tree speech "The constitution does nuarantee the right to freedom of opinion and expression. but Human Wights Watch (HRW) says this "has no effect on the daily life of the citizen" and the country "has ween a wave af arrests and violations of human rights and freedoms and mute the voices of dissent
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13.1.3 FCC website 'targeted by attack' after John Oliver comments

http://www.bbc.com/news/technology-39855490

Original Text

The US Federal Communications Commission (FCC) website was deliberately attacked on 8 May, the regulator has said. The incident began hours after comedian John Oliver criticised FCC plans to reverse US net neutrality rules. Mr Oliver urged people to post to the site's online commenting system, protesting against the proposals. The FCC said that issues with the site were caused by orchestrated attacks, not high volumes of traffic. "These actors were not attempting to file comments themselves; rather they made it difficult for legitimate commenters to access and file with the FCC," chief information officer Dr David Bray said in an official statement. "While the comment system remained up and running the entire time, these distributed denial of service (DDoS) events tied up the servers and prevented them from responding to people attempting to submit comments." 'Trolling the trolls' In his Sunday night show Last Week Tonight, Mr Oliver called on viewers to visit a website that would direct them to the correct page on the FCC site to leave their comments. "Every internet group needs to come together gamers, YouTube celebrities, Instagram models, Tom from MySpace if you're still alive. We need all of you," he said. His plea came after FCC chairman Ajit Pai said in April that he would review rules made in 2015 that require broadband companies to treat all online traffic equally. Media captionEXPLAINED: What is a DDoS attack? Last December, Mr Pai said in a speech that the net neutrality laws were "holding back investment, innovation, and job creation". "Mr Pai is essentially trolling the trolls," Chris Marsden, professor of internet law at the University of Sussex, told the BBC. "If you bait John Oliver, you reap what you sow." The FCC will vote on Mr Pai's proposals to revoke the legislation on 18 May.

Detected Text

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13.2 Code

13.2.1 Raspberry Pi

13.2.2 Smart Phone Application

13.2.3 Server

Text Extraction

```cpp
//
//  blurDetection.cpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright  2017 Portable Reading Assistant Headset for the Visually Impaired. All rights reserved.
//
//  Description: module to check whether the image (Mat object) received is blur

#include <opencv2/imgproc/imgproc.hpp>
#include "blurDetection.hpp"

// threshold value to determine if the image is blur
#define BLUR_THRESHOLD 50

//  Function: varianceOfLaplacian
//  Description: generate the variance of Laplacian for the matrix received
double varianceOfLaplacian(cv::Mat &imageGray)
{
  cv::Mat laplacian_result;
  cv::Scalar mean;
  cv::Scalar stddev;

  Laplacian(imageGray, laplacian_result, CV_64F);
  meanStdDev(laplacian_result, mean, stddev);

  return pow((double) stddev[0],2);
}

//  Function: isBlur
//  Description: determine whether image received is blur or not
//    If the variance of Laplacian of the grayscalled image is less than the threshold
//    Then the image is blurred
bool isBlur(cv::Mat &image)
{
  cv::Mat imageGray;
  double variance;

  cvtColor(image, imageGray, cv::COLOR_BGR2GRAY);
  variance = varianceOfLaplacian(imageGray);

  if(variance < BLUR_THRESHOLD)
  {
    return true;
  }
  return false;
}
```

```
//
//  blurDetection.hpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
   All rights reserved.
//
//  Description: header file for blurDetection

#ifndef blurDetection_hpp
#define blurDetection_hpp

#include <opencv2/opencv.hpp>

bool isBlur(cv::Mat &image);

#endif /* blurDetection_hpp */
```

```
//
//  getImage.cpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
   All rights reserved.
//
//  Description: module for get the image for PRAHVI
//

#include "getImage.hpp"
#include "global.hpp"

//  Function: getImage()
//  Description: function that returns an opencv Mat object - an image for PRAHVI
    to process
//    Initially setup to read from a file, need to change with ios
//    TODO
cv::Mat getImage()
{
  cv::Mat image = cv::imread("/Users/Youngestyle/Desktop/image-19.jpeg");//
    fileAddress);
  return image;
}
```

```
//
//  getImage.hpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
   All rights reserved.
//
//  Description: header file for get the image for PRAHVI

```

```
#ifndef getImage_hpp
#define getImage_hpp

#include <opencv2/opencv.hpp>

cv::Mat getImage();

#endif /* getImage_hpp */
```

```
//
//  global.hpp
//  prahvi
//
//  Created by Yang Li on 5/6/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired. All rights reserved.
//

#ifndef global_hpp
#define global_hpp

extern std::string fileAddress;

#endif /* global_hpp */
```

```
//
//  imageToText.cpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired. All rights reserved.
//
//  Description: module that converts the image received to a string of text
//    the image received is alread preprocessed
//    currently just passes the image to the google tesseract api

#include <tesseract/baseapi.h>
#include "imageToText.hpp"


//  Function: replaceString
//  Description: replace all "toReplace" with "replaceWith" in string "s"
std::string replaceString(std::string &text, const std::string &toReplace, const std::string &replaceWith)
{
  int location = 0;
  int replaceWithLength = replaceWith.length();

  while((location = (int) text.find(toReplace, location)) != std::string::npos)
  {
    text.replace(text.find(toReplace), toReplace.length(), replaceWith);
    location += replaceWithLength;
  }
  return text;
}
```

```
//  Function: replaceLigatures
//  Description: replace the ligatures with non-ligatures
std::string replaceLigatures(std::string text)
{
  // list of ligatures and non ligatures
  // the list is too long, and it is making the system really slow
  //std::vector<std::string> ligatures = {"  ", "  ", "  ", "  ", "  ",
  //  "  ", "  ", "  ", "  ", "  ",
  //  "  ", "  ", "  ", "  ", "  ",
  //  "  ", "  ", "  ", "  ", "  ",
  //  "  ", "  ", "  ", "  ", "  ",
  //  "  ", "  ", "  ", "  ", "  ",
  //  "  ", "  "};
  //std::vector<std::string> nonLigatures = {"AA", "aa", "AE", "ae", "AO",
  //  "ao", "AU", "au", "AV", "av",
  //  "AV", "av", "AY", "ay", "ff",
  //  "ffi", "ffl", "fi", "fl", "OE",
  //  "oe", "OO", "oo", "fs", "fz",
  //  "st", "ft", "TZ", "tz", "ue",
  //  "VY", "vy"};

  // thus a shorter list of common ligatures are searched and replaced
  std::vector<std::string> ligatures = {"  ", "  ", "  ", "  ", "  ","  ", "
    "};
  std::vector<std::string> nonLigatures = {"ff", "ffi", "ffl", "fi", "fl", "st", "
    ft"};

  for(int i = 0; i < ligatures.size(); i++)
  {
    text = replaceString(text, ligatures[i], nonLigatures[i]);
  }

  return text;
}

//  Function: imageToText
//  Description: receive a Mat and pass the Mat to OCR to detect the text
//    The border of the image (Mat) is removed to reduce noise
//    The OCR is initialized for English ONLY.

std::string imageToText(cv::Mat &image)
{
  std::string outText;

  tesseract::TessBaseAPI *api = new tesseract::TessBaseAPI();

  // Initialize tesseract-ocr with English, without specifying tessdata path
  if (api->Init(NULL, "eng"))
  {
    std::cerr << "ERROR: could not initialize tesseract" << std::endl;
    exit(1);
  }

  // crop the image to remove the border
  // this reduces the noise from the background
  // can use fixed pixels or with respect to width and height

  int offsetX = image.size().width*0.05;
  int offsetY = image.size().height*0.05;

  cv::Rect roi;
  roi.x = offsetX;
```

```
    roi.y = offsetY;
    roi.width = image.size().width - (offsetX*2);
    roi.height = image.size().height - (offsetY*2);

    // crop the original image to the defined ROI

    image = image(roi);

    // send the image to OCR
    api->SetImage((uchar*)image.data,
            image.size().width,
            image.size().height,
            image.channels(),
            image.step1());

    // get OCR result
    api->Recognize(0);
    outText = api->GetUTF8Text();

    // destroy used object and release memory
    api->End();

    outText = replaceLigatures(outText);

    return outText;
}
```

```
//
//  imageToText.hpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
    All rights reserved.
//
//  Description: header file for imageToText

#ifndef imageToText_hpp
#define imageToText_hpp

#include <opencv2/opencv.hpp>

std::string imageToText(cv::Mat &image);

#endif /* imageToText_hpp */
```

```
//
//  main.cpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
    All rights reserved.
//
//  Description: the system test file after the image is received
//    this file creates the prahvi object and convert the image to text

```

```
#include <iostream>
#include "prahvi.hpp"
#include "global.hpp"

std::string fileAddress;

int main(int argc, const char * argv[]) {

  int result;
  std::string text;

  /*
   if(argc < 2)
  {
    std::cerr << "ERROR: file name not specified" << std::endl;
    return -1;
  }

  fileAddress = argv[1];
   */

  prahvi myPrahvi;
  text = myPrahvi.getNewText(result);
  if(result == SUCCESS)
  {
    std::cout << text << std::endl;
  }
  else if(result == EMPTY)
  {
    std::cout << "Empty image, try again" << std::endl;
  }

  return 0;
}
```

```
//
//  prahvi.cpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright    2017 Portable Reading Assistant Headset for the Visually Impaired. All rights reserved.
//
//  Description: prahvi class
//    the prahvi class does the preprocessing and text detection
//    other program can create and call this class to get corresponding results

#include "prahvi.hpp"
#include "getImage.hpp"
#include "blurDetection.hpp"
#include "similarityDetection.hpp"
#include "imageToText.hpp"
#include "scanner.hpp"
#include "boundingBoxDetection.hpp"

//  Function: prahvi::prahvi
//  Description: constructor for prahvi
prahvi::prahvi()
```

```
{
  _previousImage = cv::Mat::zeros(1, 1, CV_64F);
  _currentText = "";
  _currentImage = cv::Mat::zeros(1, 1, CV_64F);
}

//  Function: prahvi::getText
//  Description: get the text of the current image
std::string prahvi::getText()
{
  return _currentText;
}

//  Function: prahvi::getNewText
//  Description: get a new image and process it
//    the fucntion will get a new image
//    if the new image is blur, it will terminate
//    otherwise, it will extract the text area
//    and compare to the previous text area
std::string prahvi::getNewText(int &result)
{
  cv::Mat newImage = getImage();

  //  check if the new image is blurred
  if(isBlur(newImage))
  {
    result = BLUR;
    return "";
  }

  _previousImage = _currentImage;
  _currentImage = getTextArea(newImage);

  //  check if the new image is similar to the previous image
  //  TODO - uncomment after add IDF
  /*
  if(_previousImage == cv::Mat::zeros(1, 1, CV_64F) || isSimilar(_previousImage,
    _currentImage))
  {
    result = SIMILAR;
    return "";
  }
   */

  //  convert the image to text
  _currentText = imageToText(_currentImage);

  //  reset TF-IDF and generate the score for the new document
  //  TODO - uncomment after add IDF
  //_tfidf.resetTerms();
  //_tfidf.addTerms(_currentText);

  result = EMPTY;

  for(int i = 0; i < _currentText.length(); i++)
  {
    if(!isspace(_currentText[i]))
    {
      result = SUCCESS;
    }
  }
```

```
  return _currentText;
}

std::string prahvi::getKeyword(int n)
{
  // TODO - uncomment after add IDF
  return "";//_tfidf.getTerm(n);
}
```

```
//
// prahvi.hpp
// prahvi
//
// Created by Yang Li on 4/29/17.
// Copyright 2017 Portable Reading Assistant Headset for the Visually Impaired.
   All rights reserved.
//
// Description: header file for prahvi class

#ifndef prahvi_hpp
#define prahvi_hpp

#include <opencv2/opencv.hpp>
#include "tfidf.hpp"

enum ProcessResult {SUCCESS, BLUR, SIMILAR, EMPTY};

class prahvi
{
public:
  prahvi();
  std::string getText();
  std::string getKeyword(int n=1);
  std::string getNewText(int &result);

private:
  cv::Mat _previousImage;
  cv::Mat _currentImage;
  std::string _currentText;
  // TODO - uncomment after add IDF
  //tfidf _tfidf;
};

#endif /* prahvi_hpp */
```

```
//
// scanner.cpp
// prahvi
//
// Created by Yang Li on 4/29/17.
// Copyright 2017 Portable Reading Assistant Headset for the Visually Impaired.
   All rights reserved.
//
// Description: module that extract the text area from the image
//   such that the result will be like a scanned document

#include <algorithm>
```

```
#include <vector>
#include "scanner.hpp"

//  Function: comaprePointSum
//  Description: compare 2 points based on the sum of the coordinate
//    return true if the first point is smaller than the second point
bool comparePointSum(cv::Point a, cv::Point b)
{
  return a.x + a.y < b.x + b.y;
}
//  Function: comaprePointDifference
//  Description: compare 2 points based on the difference of the coordinate
//    return true if the first point is smaller than the second point
bool comparePointDifference(cv::Point a, cv::Point b)
{
  return a.y - a.x < b.y - b.x;
}

//  Function: compareArea
//  Description: compare 2 points based on the contor area
//    return true if the first point is larger than the second point
bool compareArea(std::vector<cv::Point> a, std::vector<cv::Point> b)
{
  return contourArea(a) > contourArea(b);
}

//  Function: getDistance
//  Description: return the distance between two points
int getDistance(cv::Point a, cv::Point b)
{
  return sqrt(pow((double)b.x - (double)a.x, 2) + pow((double)b.y - (double)a.y, 2)
    );
}

//  Function: sortContours
//  Description: sort the contours based on the contour area
//    in descending order
void sortContours(std::vector<std::vector<cv::Point>> &contours)
{
  sort(contours.begin(), contours.end(), compareArea);
}

//  Function: getTextArea
//  Description: extract the text area from the image
//    Based on find the largest contour with 4 sides in the image
//    this function also transform the result found and rectify it
cv::Mat getTextArea(cv::Mat &image)
{
  // convert to grayscale and blur
  image.convertTo(image, -1, 1, 20);
  cv::Mat imageGray;
  cvtColor(image, imageGray, CV_BGR2GRAY);

  cv::Mat blurred;
  GaussianBlur(imageGray, blurred, cv::Size(5, 5), 0);

  // apply Canny Edge Detection to find the edges
  cv::Mat edged;
  Canny(blurred, edged, 0, 50);

  //  find the contours in the edged image
  std::vector<std::vector<cv::Point>> contours;
```

```
std::vector<cv::Vec4i> hierarchy;

findContours(edged, contours, hierarchy, cv::RETR_LIST, cv::CHAIN_APPROX_NONE);

// sort the contours in descending order
sortContours(contours);

// initialize the screen contour
std::vector<cv::Point> screenContour;
std::vector<cv::Point> approx;

// set screen contour to the largest contour with 4 sides
for(int i = 0; i < contours.size(); i++)
{
  double peri = arcLength(contours[i], true);

  approxPolyDP(cv::Mat(contours[i]), approx, 0.02*peri,true);

  if(approx.size() == 4)
  {
    screenContour = approx;
    break;
  }
}

std::vector<std::vector<cv::Point>> screen;
screen.push_back(screenContour);

// initialize transformation
cv::Mat lambda(2, 4, CV_32FC1);
lambda = cv::Mat::zeros(image.rows, image.cols, image.type());

// input and output coordinates
cv::Point2f inputQuad[4];
cv::Point2f outputQuad[4];

// find the max dimension of the crop
cv::Point topLeft, topRight, bottomRight, bottomLeft;

// the top left point has the smallest sum
topLeft = *min_element(screenContour.begin(), screenContour.end(),
  comparePointSum);

// the bottom right point has the largest sum
bottomRight = *max_element(screenContour.begin(), screenContour.end(),
  comparePointSum);

// the top right point has the smallest difference
topRight = *min_element(screenContour.begin(), screenContour.end(),
  comparePointDifference);

// the bottom left point has the largest difference
bottomLeft = *max_element(screenContour.begin(), screenContour.end(),
  comparePointDifference);

// set input coordinates
inputQuad[0] = topLeft;
inputQuad[1] = topRight;
inputQuad[2] = bottomRight;
inputQuad[3] = bottomLeft;

// the dimension of the output is based on the input
```

```
    // 1:1 ratio
    int width = std::max(getDistance(topLeft, topRight), getDistance(bottomLeft,
        bottomRight));
    int height = std::max(getDistance(topLeft, bottomLeft), getDistance(topRight,
        bottomRight));

    // the output coordinates is based on the output dimention
    outputQuad[0] = cv::Point2f(0,0);
    outputQuad[1] = cv::Point2f(width-1, 0);
    outputQuad[2] = cv::Point2f(width-1, height-1);
    outputQuad[3] = cv::Point2f(0, height-1);

    // set up transformation
    lambda = getPerspectiveTransform(inputQuad, outputQuad);

    cv::Mat output;

    // apply transformation
    warpPerspective(image, output, lambda, cv::Size(width,height));

    return output;
}
```

```
//
//  scanner.hpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
    All rights reserved.
//
//  Description: header file for the scanner module

#ifndef scanner_hpp
#define scanner_hpp

#include <opencv2/opencv.hpp>

cv::Mat getTextArea(cv::Mat &image);

#endif /* scanner_hpp */
```

```
//
//  similarityDetection.cpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
    All rights reserved.
//
//  Description: module to detect whether the two image received are similar
//    Currently, the method used is AKAZE tracking
//    Can be improved using matching


#include <opencv2/features2d.hpp>
```

```
#include <opencv2/imgcodecs.hpp>
#include <vector>
#include "similarityDetection.hpp"

//  threshold value to determine whether the two images are similar
#define FEATURE_THRESHOLD 1000


const float inlier_threshold = 2.5f; // Distance threshold to identify inliers
const float nn_match_ratio = 0.8f;   // Nearest neighbor matching ratio

//  Function: akazeTracking
//  Description: comapre two images and return the number of good match points
//    Uses the A-Kaze tracking
int akazeTracking(cv::Mat &image1, cv::Mat &image2)
{
  // convert the images to grayscale
  cv::Mat image1Gray;
  cv::Mat image2Gray;

  cvtColor(image1, image1Gray, cv::COLOR_BGR2GRAY);
  cvtColor(image2, image2Gray, cv::COLOR_BGR2GRAY);


  // detect keypoints and compute descriptors using A-KAZE
  std::vector<cv::KeyPoint> keyPoints1, keyPoints2;
  cv::Mat descriptors1, descriptors2;

  cv::Ptr<cv::AKAZE> akaze = cv::AKAZE::create();
  akaze->detectAndCompute(image1Gray, cv::noArray(), keyPoints1, descriptors1);
  akaze->detectAndCompute(image2Gray, cv::noArray(), keyPoints2, descriptors2);

  // use the brute force matcher to find 2-nn matches
  cv::BFMatcher matcher(cv::NORM_HAMMING);
  std::vector<std::vector<cv::DMatch>> nn_matches;
  matcher.knnMatch(descriptors1, descriptors2, nn_matches, 2);

  // if one or more of the image does not have any keypoint, return 0
  if(keyPoints1.size() <= 0 || keyPoints2.size() <= 0)
  {
    return 0;
  }

  // use 2-nn matches to find correct keypoint matches
  std::vector<cv::KeyPoint> matched1, matched2, inliers1, inliers2;
  std::vector<cv::DMatch> good_matches;

  for(size_t i = 0; i < nn_matches.size(); i++)
  {
    cv::DMatch first = nn_matches[i][0];

    float distance1 = nn_matches[i][0].distance;
    float distance2 = nn_matches[i][1].distance;

    if(distance1 < nn_match_ratio * distance2)
    {
      matched1.push_back(keyPoints1[first.queryIdx]);
      matched2.push_back(keyPoints2[first.trainIdx]);
    }
  }

  // check if the matches is within the inlier_threshold
```

```
  for(unsigned i = 0; i < matched1.size(); i++) {
    cv::Mat col = cv::Mat::ones(3, 1, CV_64F);
    col.at<double>(0) = matched1[i].pt.x;
    col.at<double>(1) = matched1[i].pt.y;

    col /= col.at<double>(2);
    double distance = sqrt(
                pow(col.at<double>(0) - matched2[i].pt.x, 2)
                + pow(col.at<double>(1) - matched2[i].pt.y, 2)
                );

    if(distance < inlier_threshold) {
      int new_i = static_cast<int>(inliers1.size());
      inliers1.push_back(matched1[i]);
      inliers2.push_back(matched2[i]);
      good_matches.push_back(cv::DMatch(new_i, new_i, 0));
    }
  }
  return good_matches.size();
}

bool isSimilar(cv::Mat &image1, cv::Mat &image2)
{
  if(akazeTracking(image1, image2) > FEATURE_THRESHOLD)
  {
    return true;
  }
  return false;
}
```

```
//
//  similarityDetection.hpp
//  prahvi
//
//  Created by Yang Li on 4/29/17.
//  Copyright   2017 Portable Reading Assistant Headset for the Visually Impaired.
//   All rights reserved.
//
//  Description: header file for similarityDetection

#ifndef similarityDetection_hpp
#define similarityDetection_hpp

#include <opencv2/opencv.hpp>
bool isSimilar(cv::Mat &img1, cv::Mat &img2);

#endif /* similarityDetection_hpp */
```

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