CIS 490 Capstone (Spring 2023) Square Vision (Team 1)

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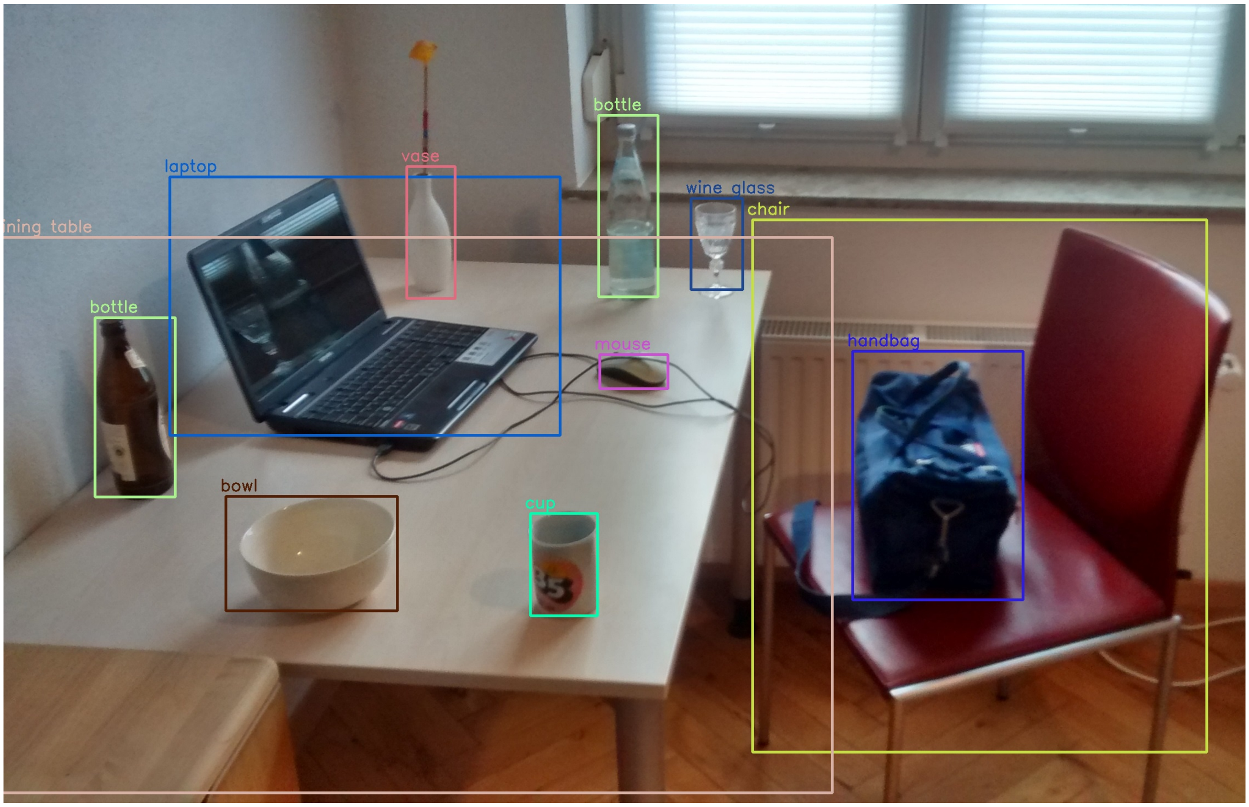

Fig. 1: Sample Object Detection

Abstract— Real-Time object recognition and computer vision are both rapidly growing research fields that have become fully integrated into multiple layers of the computer and information science industries. This expansive growth in research has made it more difficult for beginner students to learn about this growing topic. Therefore, the purpose of this paper is to introduce Square Vision as a solution to provide a foundational application for future researchers to start with an initial computer vision research project.
The two-part solution will be a standalone program and a program utilizing Microsoft HoloLens 2. Square Vision seeks to take advantage of augmented reality and real-time object recognition to offer users annotation and identification of different types of objects in the user's environment. This two-part solution will provide beginner students with fundamental tools to begin their journey in computer vision and object recognition. This project can then be taken a step further by providing potential clients such as manufacturers, educators, and first responders with a system that can efficiently and reliably identify objects of importance and relevance in each of their respective areas of expertise.

Index Terms—object recognition, augmented reality, real-time object recognition

1 Introduction

The rapid and unparalleled technological advancements of today's computer and the information age have made research into how this technology can be used and applied become even more important compared to years past. Due to the power and ability of this increasing demand and funding for research, a new technology that was not thought feasible, economic, or applicable has become commonplace and normalized.

One of these newer research areas is computer vision and object recognition. Due to this, there has been a huge increase in the application of object recognition. Research into the application of object recognition has spawned numerous advanced research projects centered around or incorporating computer vision. The main issue surrounding the research into computer vision and object recognition is the high barrier of entry as it is extremely advanced and may be difficult for undergraduate or even beginner student researchers. Therefore, it is important for researchers and educators to ensure that beginning researchers have the tools required to start their journey in computer vision research.

This presents a unique opportunity to provide an application of real-time object recognition that creates a foundation for future researchers and students that will allow students an opportunity to study computer vision. This way, it can allow more students more opportunities to

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engage in high-level research in computer vision and object recognition by giving them the introductory tools to start their research journey. It will also foster an environment of education that will pave the way for allowing computer vision and object recognition systems to become more normalized in the workplace.

The solution presented in this paper is called Square Vision and it is comprised of two main parts. The first part is a 2D application that will allow for a student researcher to start with a well-established foundational application of computer vision by allowing them to interact with basic computer vision ideas and concepts through real-time object recognition. This application shall be self-contained in Python and will allow students to run on any device that supports Python so long as they import the correct libraries. The second part of Square Vision is an Augmented Reality (AR) application that shall run on Microsoft HoloLens 2. This application shall be able to compile without error and provide the user with real-time object recognition in an augmented reality environment in a manner that will allow the user to move freely within their environment.

2 Related Works

The team used a Systematic Literature Review to evaluate related works and build the research foundations of Square Vision.

The team conducted a thorough review of available literature from a variety of sources, to include IEEE, ACM, and ScienceDirect. In order to do the research, the team conducted various quires that included specific quires on OpenCV and user-testing in Computer Science. From these initial quires, the team began to narrow down the thousands of results. To do this, the team developed the following limitation criteria:

- A Conference Ranks
- Score of B5 and C
- Extremely poorly
- Written with grammar issues

After the team narrowed down the initial results, the team them created inclusion criteria that the papers and conferences had to meet in order to be included in the paper. These inclusion criteria are:

- Well referenced
- On topic with formal search query
- Conference ranks score being above B5 and C
- Providing a reasonable foundation for the team for either a current feature or a planned feature

After these exclusion and inclusion criteria were applied, the team was left with a much more manageable amount of data to work with. This data is the foundation of the team's full research paper. The final set of selected resources have been instrumental in the development of Square Vision. These resources can be divided into multiple categories: Real time object recognition, HoloLens with OpenCV, OpenCV and Python, and User Testing in Computer Science.

2.1 Real Time Object Recognition

At its core, Square Vision is about real time object recognition, the concept that object that are viewed by a computer can be distinguished and recognized in real time similar to how humans and animals are able to distinguish between different objects. One of the most popular ways this can be achieved is through convolutional neural networks (CNN). CNN are used to power countless object recognition programs and software. In some cases, they are applied in high risk environments such as healthcare diagnoses thus proving that they are able to successfully and rapidly identify objects in life or death scenarios [21].

Square Vision's real time object recognition capabilities is powered by OpenCV, which is a CNN application. OpenCV is an open-source computer vision library that utilizes Haar classifiers to identify objects [24]. OpenCV is capable of being implemented and utilized in the Python, C++, and Java programming languages. The CNN-powered OpenCV library is currently implemented in many real-world applications such as robotics, security cameras, video games, and manufacturing to name a few [19]. One such example of an OpenCV application that has been deployed in the field is the one that was trained to identify explosive devices in the field. This particular project was developed using Python, Javascript, C++, and Java. The application is able to run on a laptop and be taken into the field to identify potential improvised explosive devices and military explosive devices [15].

OpenCV is also capable of running on mobile devices but OpenCV does not necessarily require a server-side application to identify objects. Mobile devices in this context also refer to iOS devices [17]. The results of the systematic literature review indicate that the field of real time object recognition is growing rapidly in the context of demand and innovation.

2.2 OpenCV and Python

The 2D implementation of Square Vision was developed entirely in Python. While Python is generally a slower programming language compared to C and C++, Python is able to be extended by C and C++. This allows Python give computationally heavy codes to C or C++ which allows it to run just as fast as either of those languages. This is a significant advantage as Python is an objectively easier language to learn compared to C and C++ [14].

Another reason why Python was the selected development language is that it can be executed on any device that has a Python compiler. These platforms include iOS, Android, Mac OS, Linux and, Windows devices [1]. Due to its ability to utilize C and C++ along with its multi-platform capabilities, Python is able to take full advantage of OpenCV's features and capabilities. Some of examples of what OpenCV and Python can do are image manipulation, pattern detection, eye tracking, image extraction, object mapping, and depth perception [10]. Python's OpenCV is capable of supervised learning. This means that more objects can be added to the list of distinguishable objects.

It is worth noting that real time object recognition with Python's OpenCV library has some potential limitations. For instance, the accuracy of identification is dependent on the resolution of the input camera [6]. The frame rate during the real time object recognition is also directly associated with the input camera's frame rate in combination with the host system's CPU power [7]. Despite these potential limitations, the decision to implement Square Vision with Python was easy to make based on the amount of research, products, and documentation available.

2.3 HoloLens with OpenCV

The Augmented Reality implementation of Square Vision was desgined for the HoloLens2. The HoloLens and HoloLens2 make use of Unity assets to create "holograms" that the wearer can see in an augmented or mixed reality environment. The HoloLens and HoloLens2 are capable of using OpenCV libraries. For example, a mixed reality board game "Mensch ÄRgere Dich Nich" makes extensive use of OpenCV libraries to reads dice and read player positions on a board [12].

The HoloLens and HoloLens2 have both seen limited real world deployment. One such application of the HoloLens is in the field of education where it has been used as method to save school systems money in Special Education Programs [22], STEM labs and, music education [25]. It also plays a critical role on blue collar trade training [26]. However, the HoloLens has seen some deployment in some high risk fields such as surgery. In the United States, a team of researchers were able to have the HoloLens accurately display a "hologram" of an MRI over a patient's breast tissue in an effort to accurately identify a surgical entry point for a cancerous tumor removal [20].

Due to the ability of the HoloLens to keep "holograms" in a stable location, researchers have looked into more applications for the device. One such application was an augmented reality object recognition software. The HoloLens2 is capable of tracking its environment, similar to OpenCV's ability to track depth and edges in a room. The HoloLens2 is able to support machine learning algorithms hosted on an server. Moreover, it is capable of real time object recognition [11]. Current implementations and research into developing a real time object recognition software utilize the C# and C++ programming language in combination with Unity 3D assets [5]. Project such as these served as an inspiration to attempt to implement Square Vision on the HoloLens2.

2.4 User Testing in Computer Science

A program written in a void has no foundation or standing if it can not be used or has never been tested by users. Therefore, Square Vision needed to undergo a well thought out and systematic user-testing. This testing needed industry recognized questionnaires, be paperless, and give the team feedback data that can be used to improve Square Vision. In order to accomplish this, research was done with the express purpose of providing a systematic approach to user testing and providing foundational research to the entire user-testing.

Therefore, the Square Vision user study team utilized both the National Aeronautics and Space Administration Task Load Index (NASA-TLX) and the NASA System Usability Scale (NASA-SUS) questionnaires [13] to asses the software's usability and ease of use. According to the National Library of Medicine, the NASA-TLX questionnaire allows for pooled analysis of gathered data [18]. These two questionnaires are the gold standard for user testing in Computer Science, and allows for cross discipline data analysis [8]. Prior to conducting the tests, the subjects were required to read, retain, and submit an informed consent document in order to protect not only the test subject's rights but also the testing team's rights [16].

The participants of the user studies for Square Vision consisted entirely of college-aged males and females. This was done in order to provide a more diverse and inclusive perspective on the Square Vision product and its potential applications [23]. Additionally, the testing group who underwent the user studies also spanned multiple different academic departments in order to diversify the background knowledge of the participants [9].

The entire process was done through the Qualitrics online survey software. This allowed the user-testing to do done with no physical documentation and allowed for limited interaction with an Testing Administrator from the team. [3] [2] The guidance from these papers have allowed the Square Vision research team to successfully conduct user testing.

3 Problem Description

As today's society progresses further and develops more complex and advanced technology, there is a greater need for AR object recognition. In particular, real-time efficient and accurate AR object recognition will play a more critical role in the future. Many different applications of AR have been created in the past utilizing cell phones, laptops, and other devices with camera technology. However, there needs to be more representation of real-time object recognition via AR.

An in-depth research and analysis of related works indicated that there is a large need for providing more opportunities for research, testing, learning, and creating in reference to AR Object Recognition. Many students and professors as well as other people interested in learning topics within the topic of computer science can benefit from the use of this AR object recognition software. In order to contribute to the future of AR technology, it is vital that Square Vision be implemented in a manner that is not only effective and efficient but also simple and accessible. With the use of HoloLens 2, the user experience shall be user-friendly. This product shall be useful and viable for a learning and training environment because it does not hinder the learning process by making a difficult user interface. The user shall simply put on the HoloLens 2 and begin using the Square Vision application

By developing AR Object Recognition software to be used in conjunction with the features of the HoloLens 2, a very useful and important teaching device will be created for the use of anyone. The opportunities are endless when it comes to AR. The plan for this software is to be used in any work environment, whether that be in the Operating Room for a Surgeon, a construction zone for an architect, or even a classroom for a student. The possibilities are numerous and extremely beneficial for all users that are involved.

Augmented Reality annotation, paired with object recognition, is in high demand for its many real-world applications. Utilizing the Hololens 2, square vision also seeks to address visual impairment and distance work and learning. Visual Impairment covers a wide variety of situations in which potential users of square vision will attempt to mediate. The effects of geriatric visual impairment can be mediated by recognizing objects and annotating them for geriatric users to help them understand and comprehend their environment. Construction workers, first responders, the military, and other occupations that require work in hazardous areas often suffer from a lack of environmental awareness due to the high-stress situations they find themselves in. Augmented Reality annotation can help identify hazardous objects or scenarios and give context to the user so that they may better operate in hazardous environments. Augmented Reality annotation can also assist in distance work and learning. The medical, assembly and learning fields are all exploring distance work and learning following the COVID-19 pandemic. In the medical field, doctors are attempting to implement robotics and augmented reality to perform surgeries from across the globe. Camera Augmentation can be used to assist doctors during surgeries by identifying key organs or surgical tools that may be hard to identify after use. Augmentation of the real world can also assist assembly workers in identifying objects through a camera that they may not be aware of or have missed in the assembly process. Augmentation can help guide the assembly process as studied, research and development on this exact process have begun, but is still in the early stages [4]. The educational field has been long attempting to use virtual reality to assist in the learning experience, especially in the adolescent and language learning stages of study. With square vision making use of the Hololens 2, augmented reality annotation can be used to identify and or translate objects, signs, and text for the users so that language or simply adolescent learning barriers [22].

Square Vision specifically, is focused and revolved around efficiently creating a learning environment for the user. It is developed for users of many occupations and statuses throughout society. The purpose behind Square Vision directly reflects solving some of the problems that have been discussed in previous sections. The main problem that Square Vision aims to fix is the lack of research, testing, learning, and creating in reference to Augmented Reality Object Recognition. Square Vision aims to address these problems by being able to operate in any environment that could benefit the user for their specific situation.

4 Proposed Approach

Square Vision has a unique design in that it is utilized through the HoloLens 2 system and a independent 2D Python application. The use of Augmented Reality Object Recognition is the main focus of the software. When booted up and fully running, the system will be able to identify different objects within the User's field of view. Items can range from clocks to computers and even humans to chairs. Not only can Square Vision identify an object, but it can identify multiple objects at the same time. Labeling them in real-time as the User navigates through their environment.

The user interface shall be made to be as simplistic and accessible as possible. This makes it more desirable for all users regardless of age and technological experience, another reason that this is a great learning tool for users. The prompting screens contain less than three buttons each making the screen as clutter-free as possible in order to help guide the user. When the main Object Recognition feature is in use, objects are identified by squares that outline them. These thin-lined squares identify the objects and track them in real-time as the user moves through the area of use. Directly above the square is a label that describes the name of the object. The lettering is clear and readable without taking up too much space or distracting the user.

The team decided that the proposed system would be a open-sourced even playing ground that allows for student research and enthusiasts alike can have a better base-line starting point. Our unique approach first began with how the team decided to cull high-quality peer-reviewed works.

To gather these works, the team conducted a thorough review of available literature from a variety of sources, to include IEEE, ACM, and ScienceDirect. In order to do the research, the team conducted various quires that included specific quires on OpenCV and user-testing in Computer Science. From these initial quires, the team began to narrow down the thousands of results. To do this, the team developed the following limitation criteria:

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After these exclusion and inclusion criteria were applied, the team was left with a much more manageable amount of data to work with. This data is the foundation of the team's full research paper.

Once the foundational research was established through the above processes, the team's main Python developer chose to break the code storage down by Sprints. Allowing for the entire team access to each sprints development and allowing for the team to roll back to previously working code if needed. This included the use of a GitHub repository that allowed for more than one member of the team to work on the Python application without worrying about the team members being on different pages.

The final unique approach about our deliverable was the inclusion of the HoloLens2 port. This allowed for students and enthusiasts alike to not only interact with a high-level Machine Learning algorithm and Open-CV, but also allow them to have an Artificial Reality experience along with the Machine Learning algorithm.

5 Evaluation and Discussion

At the end of each sprint, the team evaluated the end result with the following criteria:

- Square Vision will be able to compile without error.
- Square Vision will be able to identify objects with 75 percent accuracy.
- Square Vision will be able to distinguish objects with 75 percent accuracy.
- System Initialization: System turns on
- User: Tells system (through button or voice) to begin identifying objects.
- System: begins to identify objects, and reports back to the user.
- User: Looks around the environment, and repeats step 3 until the user tells the system to stop running. System: turns off.

  After development, Square Vision more than met the above goals. The team is very happy with the end products as seen in Figure 3 and Figure 4.

This solution was tested over the course of multiple weeks with over 20 different students testing the product. Their areas of study were:

- Civil and Environmental Engineering
- Computer Information Science
- Economics and Business
- Electrical and Computer Engineering
- History
- International Studies
- Mechanical Engineering
- Psychology

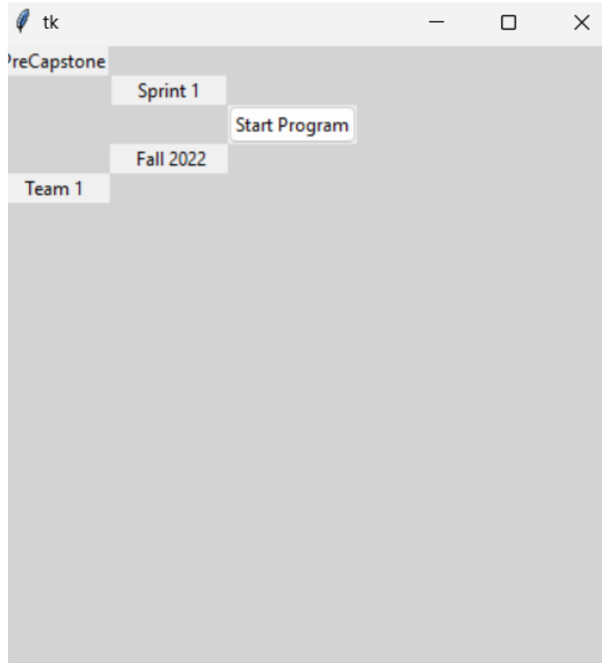

Fig. 2: Version 1.0 of Square Vision GUI

They were asked to fill out both the System Usability Scale (SUS) and NASA Task Load Index (TLX) questionnaires. Due to a technical issue associated with the VMI IT department, the data associated with the user-studies is not accessible to the team. Beyond the formal user-studies that were conducted, the team also received feedback from Dr. Gracanin and Dr. Azab and LTC Lasisi and unofficial feedback was received from other participants. This feedback was unofficial and was given to the team is written forum. A synapses of that data is below:

- The GUI is simplistic
- The color choice should be changed
- Look at expanding the algorithm to recognize more objects

The initial design of the system is seen in Figure 5. Figure 5 shows the latest 5.0 version of the GUI of Square Vision.

Figure 6 shows the updated GUI that the testers will evaluate as a part of the overall evaluation process.

Figure 10 shows the Hello World program in Unity. Due to ongoing development, there is no image of the current HoloLens2 port.

Square Vision is a highly ambitious project for the team as it incorporates two fields of computer science that no one on the team were particularly proficient in: virtual reality and object recognition. Due to the fact that nobody on the team had experience with virtual reality or object recognition, a majority of the initial work to do was research and learning.Figure 10 is an image of the team conducting research on the topics. The team spent many hours in the Pre-Capstone and Capstone courses and in their own time researching how to implement the component parts of Square Vision.

6 Epilogue

6.1 Conclusion

Square Vision is an augmented reality object recognition software that utilizes the system functions of the HoloLens 2. It can identify and label multiple objects at one given time within the user's field of view. It was developed to aid in a learning environment for users of all technological experiences. Through the use of augmented reality on the HoloLens 2 this two-part solution will provide beginner students with fundamental tools to begin their journey in computer vision and object recognition. This project can then be taken a step further by providing potential

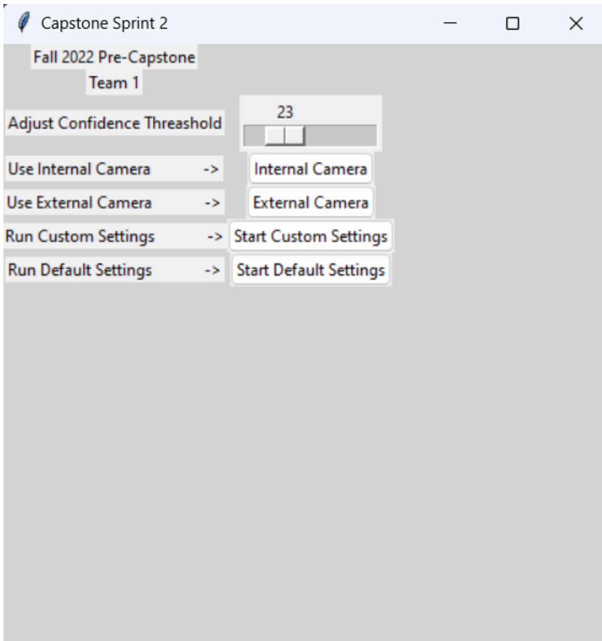

Fig. 3: Version 2.0 of Square Vision GUI

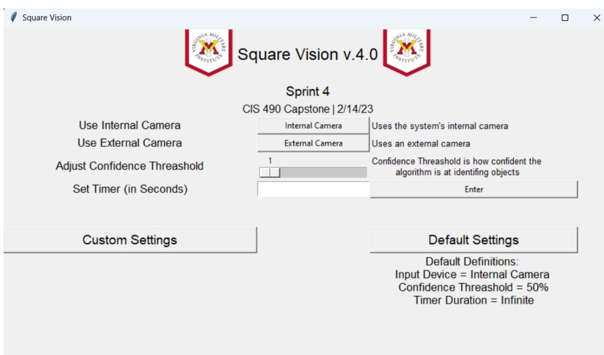

Fig. 4: Version 4.0 of Square Vision GUI

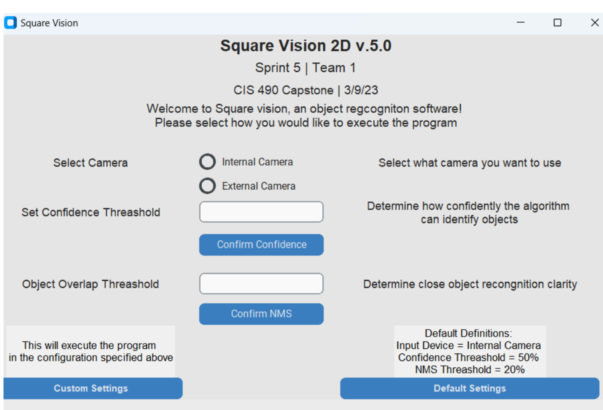

Fig. 5: Version 5.0 of Square Vision GUI

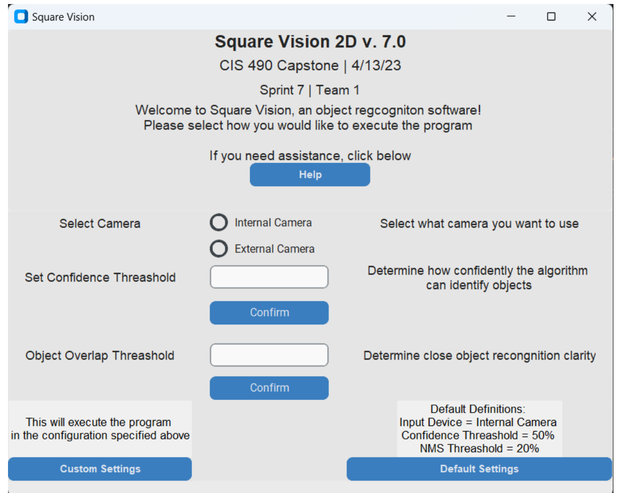

Fig. 6: Final Iteration of Square Vision GUI

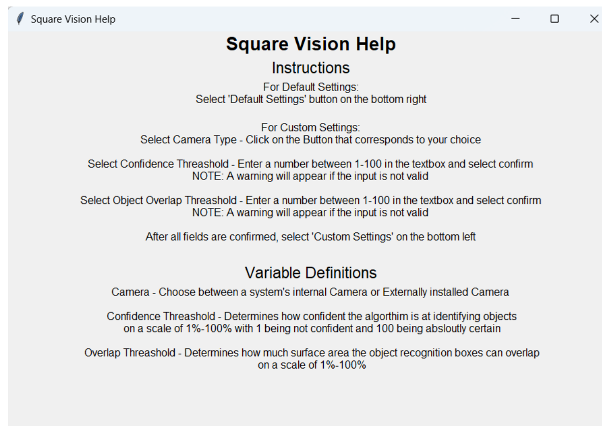

Fig. 7: User Assistance Button

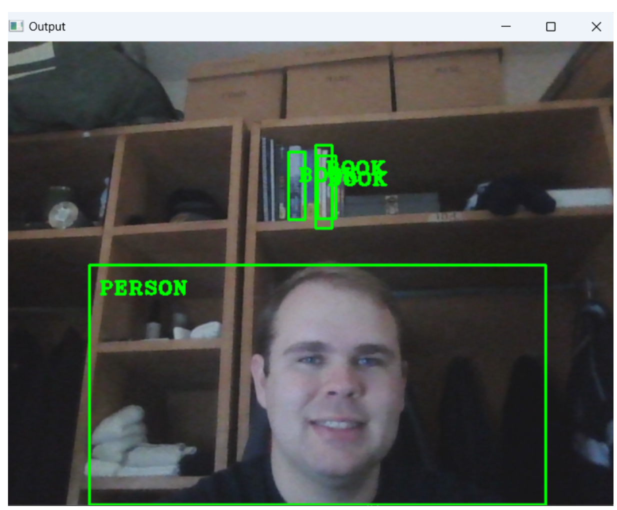

Fig. 8: Initial Output of Square Vision

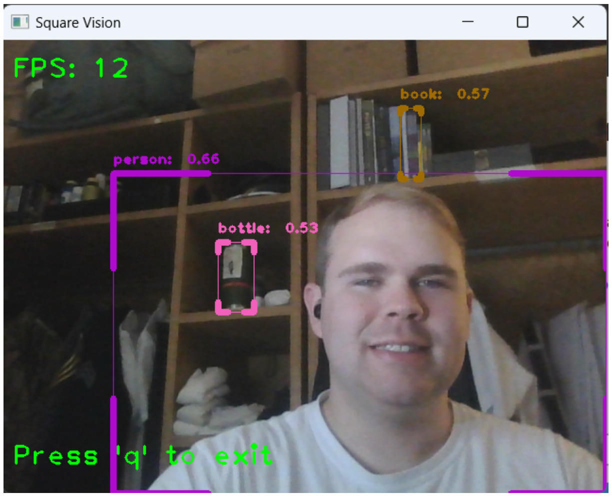

Fig. 9: Final Output of Square Vision

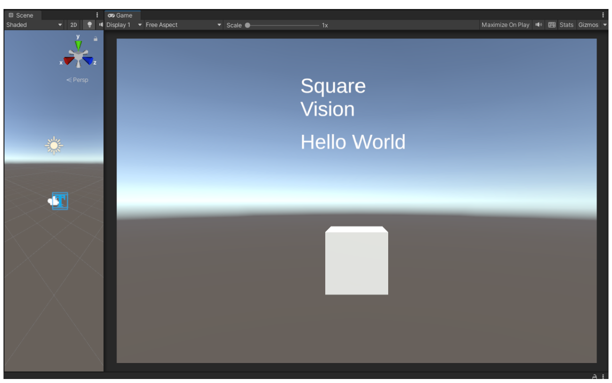

Fig. 10: Result of the initial proof of concept SquareVision application on the HoloLens2

Fig. 11: Result of the current SquareVision application on the HoloLens2

clients such as manufacturers, educators, and first responders with a system that can efficiently and reliably identify objects of importance and relevance in each of their respective areas of expertise.

6.2 Acknowledgment

Throughout our development process, the team received a lot of help and guidance from different members within the computer science community. We would like to thank Dr. Gracanin for his continuous support and advice through our progress with this project, Dr Azab for his thoughts and agreement to act as one of the team's customers, and Dr. Ghani for being the team's Capstone advisor. From assistance with the user experience as well as the documentation, it has been an enormous help. Additionally, we would like to thank Dr. Ghani who is our project advisor. They have helped with pointing us in the right direction when developing our project and supervised our progress. Finally, we would also like to thank the people who volunteered to help us test both the initial and final Square Vision proof of concept and the members of CIS 480 Pre-Capstone Section and members of the CIS-490 Capstone Section on for their feedback and comments on the project.

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6.4 Appendix

Throughout the development of our project, we utilized code repositories that are located on GitHub. The code repository is a storage location for our code and other software development assets, such as documentation, tests, and scripts. It was used to manage and organize our software project's code base and collaborate with other team developers. This allowed for more than one member of the team to work on the Python application without worrying about the team members being on different pages. These repositories were submitted on a different assignment.

The team also created web pages on Canvas that documented multiple different aspects of the project and information for our project. This includes web pages that discuss the 2D application, augmented reality application, introduction to Square Vision, and then a Team member page.

The 2D application web page defines the description of the application as well as the user-controlled variables. This entails the definition of our confidence threshold, NMS threshold. and the internal/external webcam. Additionally, it entails the imports and downloads that we utilized to create our 2D application. These are available as well as our previous and current 2D implementation on the GitHub repository.

The augmented reality application web page illustrates the product details of the HoloLens2. It covers the description, user-control development, product feedback, and a short proof-of-concept video that demonstrates the features of the HoloLens 2. This webpage also defines the voice control, gesture control, and eye tracking features that are implemented within the hardware of the headset.

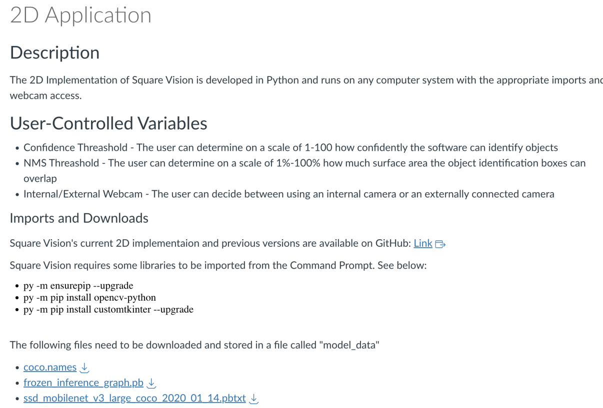

Fig. 12: 2D Application Web Page on Canvas

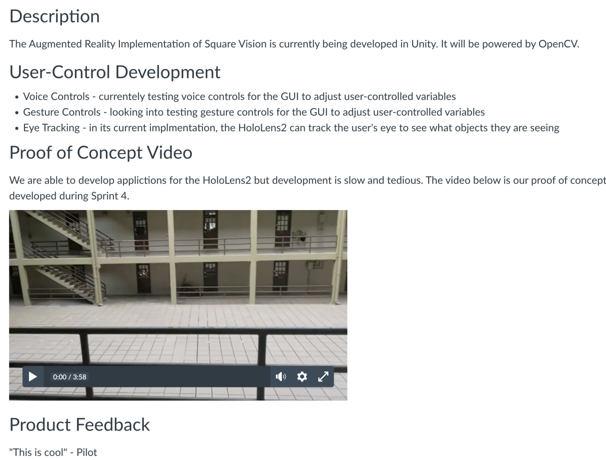

Fig. 13: Augmented Reality Application Web Page on Canvas

The introduction to the Square Vision web page entails a description of Square Vision itself, its features, product details, and background motivation. The features that it defines and links to sources are OpenCV, Python, locally stored libraries, not server dependent, and it runs on computer systems with a Python compiler as well as HoloLens2. The product details section within this web page talks about the two different versions of Square Vision.

Lastly, the team web page introduces the members of this project. It breaks down what each team member is responsible for and their contributions to the project. It also introduces the Capstone advisors that oversaw our project development throughout its course. The Capstone instructor for our project was Dr. Denis Gracanin and the Capstone advisor was Dr. Imran Ghani.

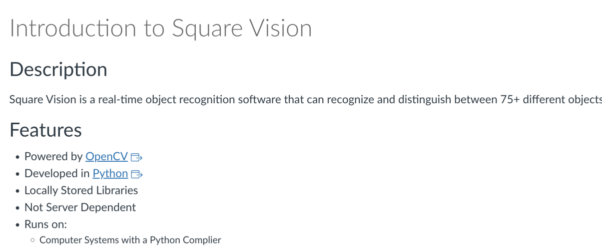

Fig. 14: Introduction to Square Vision Web Page on Canvas

Team Members

Connor Holland '23 - Documentation, Recruitment, and Research

John Barker '23 - Documentation and Product Testing Overseer

Ian Salyers '23 - HoloLens2 Developer and Documention

Peyton Wiecking '23 - Team Lead, Python Developer and Documentaion

Fig. 15: The Team Web Page on Canvas