Bluetooth Endoscopy Capsule

PROJECT DOCUMENT

SDDEC23-19
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Executive Summary

Development Standards & Practices Used

A key development standard that we utilized was the use of version control to ensure that all work was properly backed up and maintained. We utilized Git for our version control and always utilized new branches for any new features or bug fixes that were implemented. Only after ensuring that this code passed all relevant tests at the minimum coverage and success rate were these branches then merged into the main branch. By utilizing this strategy, we ensured that no code would accidentally be lost or overwritten and always had backups in case a new feature was to cause the application to stop working properly.

Summary of Requirements

The product should

- Send image information from the gastrointestinal tract to the desktop via Bluetooth.
- Use image analysis on the images received to detect if there is an ailment present within the gastrointestinal tract.
- Display to the user that an ailment is present and show the user where the ailment is detected at.
- Have the capability to withstand the temperature and pressure of the human gastrointestinal tract.

Applicable Courses from Iowa State University Curriculum

- EE 201 – Electric Circuits: Provided the circuit element and analysis knowledge needed to construct the hardware.
- EE 230 – Electronic Circuits and Systems: Frequency vs time domain characteristics of circuits.
- CprE 288 – Embedded Systems 1: Provided general knowledge of microcontrollers and GPIO ports.

New Skills/Knowledge acquired that was not taught in courses

- Python
- OpenCV
- PyTest
- Sockets
- C#
- WinForm GUI
- Nordic SDK

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1 Team

1.1 Team Members

- Jon Thomas – Electrical Engineering
- Robert Zukowski – Electrical Engineering
- Chase Thompson – Software Engineering
- Cutler Thayer – Computer Engineering

1.2 Required Skill Sets for Your Project

- Complex circuit design.
- Knowledge of advanced algorithms and AI
- Ability to research and utilize electrical components (i.e. pH sensors, cameras, etc.)
- Front end programming for the UI of the application interfacing with the pill
- Knowledge of microprocessors

1.3 Skill Sets covered by the Team

Robert Zukowski: Electrical Engineer of the high frequency variety. Most likely to contribute to any Bluetooth, antenna, or communication related project sections. Also has significant experience with PCB design and manufacturing as well as a very strong coding background.

Cutler Thayer: Computer Engineer with a specific interest in embedded systems. I will likely be in between the hardware and the software as I have decent experience in both. I have a strong background in developing software applications while also building hardware projects on the side.

Tucker Thomas: Electrical Engineer interested in VLSI design. The best location for me would be circuit or mechanical design. I am best in a hands-on environment, and love building things that are tangible. I will be able to contribute to software development, though likely with less success than others.

Chase Thompson: Software Engineer who has a background working with embedded systems. I will be working on creating the on-board software for the capsule and the computer application that interfaces with the capsule over Bluetooth. Most of my efforts will likely be applied in utilizing AI to analyze the data captured by the capsule.

1.4 Project Management Style Adopted by the team

We are using a mixture of the waterfall and agile project management styles to get the benefits of having a more linear style but also utilizing the ability to change the project as we go along should we run into issues. We will all hold the same level of priority as one another to ensure one voice does not overpower the rest. We will maintain a professional relationship between ourselves and address problems or lapses in communication as a group rather than trusting that a group leader can have all the responsibility piled onto them. All members should equally build leadership skills by communicating effectively and playing their part.

1.5 Initial Project Management Roles

We will be basing our project on the agile/waterfall structures however we will be putting them into effect in a more relaxed method without instructing anyone into any specific leadership role. The closest thing we have to a managerial position is the one person in charge of emailing/contacting the professor, but this communication will still be equally vetted by other team members. The person in charge of communicating with the professor might change from week to week.

2 Introduction

2.1 Problem Statement

Doctors struggle to diagnose various ailments that may occur in their patients' gastrointestinal tract. This struggle occurs because current methods are expensive and time-consuming. Most current methods of testing and diagnosis involve more invasive methods like endoscopic cameras, x-rays, and CT scans. While these methods have their merits, doctors need to be able to diagnose these issues autonomously without having to subject their patients to invasive testing.

2.2 Intended Users and Uses

The intended users for this device are doctors investigating issues in a patient's gastrointestinal tract. By using this device, it would allow for easier diagnosis of colon cancer and ulcers than traditional methods. The device would end up inside a patient by them ingesting it and letting it run through their gastrointestinal tract for 8-12 hours. After the device leaves this tract, the doctor will be presented with specific images that the device detected may contain signs of ulcers or colon cancer allowing for less time to be spent on diagnosing the patient.

2.3 Requirements & Constraints

For this project, the device must be no larger than the size of a standard pill. All electronic components must be able to fit inside of this space while being able to collect and transmit data via Bluetooth to a GUI application on a smartphone, tablet, or computer. The electronics used in this device must be off the shelf electrical components to keep manufacturing costs as low as possible. By sticking to off the shelf electronics, more time can also be allocated to more important tasks, such as improving on features that capsules already on the market provide to grant a more competitive advantage. The capsule must be safe for humans and animals to swallow and must not carry a risk of dissolving or rupturing the inside of the user.

2.3.1 Functional Requirements

- The capsule will be able to receive data from an image sensor.
- The capsule will be able to send image data over Bluetooth.
- The desktop application will receive images over Bluetooth.
- The desktop application will analyze gastrointestinal images for signs of ailments and categorize them based on ailments detected.
- The desktop application will display the camera view and flagged images to the user.

2.3.2 Non-Functional Requirements

- All electronic components must fit within a standard 000 size capsule.
- The desktop application should be able to work with a USB endoscope camera.
- Analysis of an image frame must be completed before another image frame is received.

2.3.3 Operating Environment

- The capsule will be able to withstand the expected conditions of the human gastrointestinal tract.
- The desktop application will be able to run on a standard desktop computer.

2.4 Engineering Standards

Device Specialization - Endoscopic Camera

This provides the standard for an endoscopic camera. These cameras are usually inserted through the throat to see the inside of the body during various surgeries and operations. While we would not need to understand this standard exactly, we need to look at this to see the camera standards to make sure that the cameras we may add to any device match the correct standards and are safe to use by medical professionals.

Point-of-Care Medical Device Communication

This is an extremely broad standard that covers a lot of different medical devices. Since the end goal of the project is to simulate a medical device that would measure various things it would make sense to have those same standards in mind when working on this device. When looking at the standards for the many devices covered by this framework, we can see similar standards that we should abide by to make things safer and easier.

3 Project Plan

3.1 Project Management/Tracking Procedures

We will adopt the agile leadership style as it is better for a team relationship. It's better to lead by example than it is to facilitate people. Also, our tasks will naturally be divided by our expertise, so it may not be best to have one person in charge of the entire project. Every team member should still be in the loop with project goals outside of their expertise, however.

To track our project's progress throughout this course, we will use Git and Trello. Git will be used as our place to store code and documents that are important to our project and Trello will be used to keep track of current tasks, future tasks, and any issues that may come up for each task.

3.2 Task Decomposition

We have decided to divide our project into three smaller teams to work in tandem while still adopting an agile management style. The reason we decided to do this is so part of the team can make progress with the physical aspect of our project while the other part works on the software. Without splitting into multiple smaller teams, part of the team would potentially be waiting for the creation of the hardware to be completed before being able to begin work on the software.

The smaller tasks that we have split the project into is the creation of the circuit layout, the desktop application, and the firmware. The team that will be responsible for the firmware and desktop application are the same, however, the creation of the firmware will take place in tandem with the creation of the circuit after the desktop application has had substantial progress. These smaller tasks can also be split up into smaller tasks that will be progressed through with an agile workflow style by completing the earlier tasks before reviewing and then moving on to progress on the next tasks.

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

As described in section 2.2 Task Decomposition, we have split the project into three smaller tasks on their own. Within these three tasks are milestones that we intend to progress through using the agile workflow. After completing one milestone for a task, the team will then move onto the next milestone. Should any issues be found with the current milestone, they will be addressed and fixed before moving on to the next milestone. A breakdown of these milestones can be found below.

1. Creation of Firmware
    1. Take data from components.
    2. Transmit data to desktop application.
        1. USB/File (for prototyping)
        2. Bluetooth (final)
2. Creation of Circuit
    1. Find components that fit project requirements.
    2. Refining those components to fit in size constraints.
    3. Create a prototype.
3. Creation of Desktop Application
    1. AI to analyze colon images.
    2. Displaying of data
    3. Receive data over Bluetooth

3.4 Project Timeline/Schedule

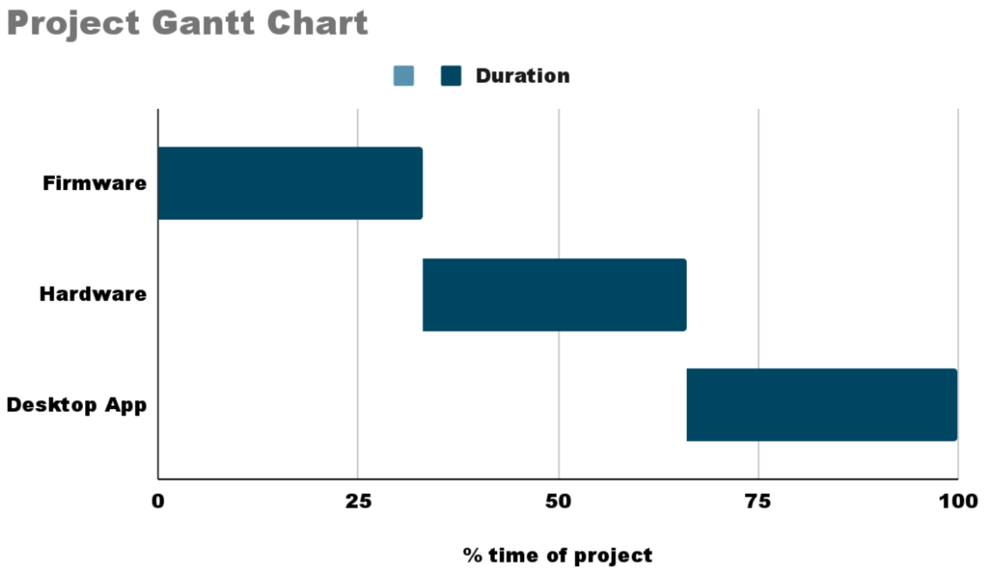


Figure 1 - Project Gantt Chart

3.5 Risks and Risk Management/Mitigation

Major Task	Risk	Probability	Risk Mitigation
Firmware	Unable to transmit data through Bluetooth while capsule is inside of the patient	0.7	Find a way to transmit the data after the capsule has left the body
Circuit	Unable to fit in the size constraints	0.5	Remove components that are less important to shrink the capsule size
Hardware	Capsule provides risk of bursting	0.2	Test capsule in specific extreme environments
Software	Unable to create an image processing algorithm with a success rate about 70%	0.5	Lower the success rate of the automated detection but provide images afterwards that allow the user to manually check the algorithms work

Figure 2 - Risk and Risk Management Table

3.6 Personnel Effort Requirements

Major Task	Minor Task	Person Hours	Explanation
Firmware	Retrieve data from components	5	This task will likely take a large amount of time to research how to write firmware for the microcontroller we use.
Firmware	Send data to desktop application	8.5	This will likely take a substantial amount of time to determine how to send data to the desktop app while ensuring it receives the data properly.
Software	Image processing	40	This will likely be a time-consuming process as a lot of research will need to be done to learn about image processing in general while also learning about the visual signs of the cancer and polyps that we are detecting. It will also likely take time to fine tune and improve the algorithm after a baseline is created.
Software	Receive BT data	8.5	This will likely take a substantial amount of time to get properly working in tandem with the firmware
Software	Display data	10	This will take a decent amount of time due to having to set up the base desktop application while relying on receiving the data to even work.
Circuit	Find components	7.5	This will take a decent amount of time as the team will have to decide what sensors are needed and where to source them
Circuit	Refine components list to fit within size constraints and price constraints	20	This will take a substantial amount of time as finding small components for cheap can be quite difficult. The team will also have to consider which components are less important to save space.
Circuit	Create prototype	30	This will be the most time-consuming portion for the circuit team as they will need to find out how to fit all the components into the capsule and create a working prototype for testing.

Figure 3 - Effort Requirements Table

3.7 Other Resource Requirements

Besides financial resources, for this project we will need image data banks and a false intestinal tract. The image data banks will allow us to use images to test our image processing algorithms and fine tune them throughout the project. The false intestinal tract will allow us to test the full capsule when we have a working prototype to ensure that it works properly and determine whether it is safe to test on animals or if more improvements need to be made.

4 Design

4.1 Design Context

4.1.1 Broader Context

Area	**Description**	**Examples**
Public health, safety, and welfare	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities)	The safety risks with ingesting our endoscopy pill are related to the safety risks associated with swallowing a battery. While that sounds bad, the capsule should be enough to protect users' stomach lining from the battery inside the pill. The pill also reduces job opportunities by removing the need for certain specific endoscopy tools.
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.	Implementation of our capsule would require individuals to be open to the idea of ingesting a circuit, which will be a difficult hurdle for users to overcome. However, the pill is designed to be used in the biomedical field. Therefore, if it can be proven that the solution is safe and effective, it would be a net-positive for doctors and patients alike.

Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.	Implementation of the pill would have a net-negative impact on the environment. This impact could be in the form of municipal solid waste or energy usage. Many circuit components aren't recyclable resources, and the energy source (silver oxide battery) is non-renewable.
Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	While it is difficult to determine manufacturing costs related to this solution, the parts involved would be much less than the cost of an endoscope (>$10,000). Capsule prices are currently very expensive, but if the cost were to be reduced to sub $100, the procedure would become much more affordable. More effort is needed to determine exact costs. This is partially because of the complex financial relationship between doctors, patients, and insurance companies.

Figure 4 - Design Context Table

4.1.2 User Needs

Gastrointestinal Doctors need a way to examine patients safely and effectively for early signs of disease because current methods are invasive and time-consuming.

Gastrointestinal Patients need a way to monitor the health of their stomach to catch early signs of disease to avoid expensive and invasive endoscopies.

4.1.3 Prior Work/Solutions

Capsule endoscopy is by no means a revolutionary project. Many companies already make pills with very advanced circuitry or capture technology, and there is plenty of research on basic capsules that exist. The biggest disadvantage of all the existing technology is that a significant amount of it is locked behind corporate offices that are not keen on sharing their advancements with the rest of the world. Our project revolves around creating a generic capsule that performs up to the expected standards while remaining as cheap as possible - current capsules cost between $600 and $1300 which is a completely unrealistic cost for this type of product.

https://www.howmuchisit.org/capsule-endoscopy-cost/

There is also much to be gained from replicating and publicizing certain technology such as rapid reading software or sending data from the pill without a large Bluetooth/microcontroller IC and battery. These technologies also already exist but again are locked behind corporate secrets.

4.1.4 Technical Complexity

Our project has three main components. In no order, the first component is the creation of firmware that takes data from components and transmits it to a desktop application. This will be done through Bluetooth, but some wireless transmission solution will be required to send data from within a person to a computer. This requires embedded programming skills, as the transmission will be from a microcontroller within the capsule the same way that most if not all currently existing capsules solve the same problem. The next component is a circuit that fits as many sensors as possible into the size constraint of the capsule. This requires a good knowledge of selecting compatible components as well as circuit creation in general. This circuit also must work together with the transmission firmware. Finally, the third component is the creation of a desktop application that will receive the Bluetooth data from the capsule firmware and display measured results using AI. This part of the project requires a strong understanding of coding principles and a good understanding of AI. This firmware should be able to compete with existing industry solutions.

4.2 Design Exploration

4.2.1 Design Decisions

- Nordic Semiconductor will be used for the main microcontroller within the capsule.
- Any sensors to be used are provided by the advisor.
- Physical Layout will be done with discrete wires (no PCB) and must all fit within the capsule.
- Code for the desktop application will be done with C++ while the image processing will be done with Python.
- The desktop application will implement image processing regardless of if we are able to transmit camera data from the capsule itself.

4.2.2 Ideation

The physical layout was chosen out of a desire to limit the size of the capsule. PCBs require a lot of space compared to simply the microcontroller, connected to sensors with wires.

4.3 Proposed Design

Currently we have not implemented or tested any aspects of our physical capsule or the software for the desktop application. We are still researching components and implementation techniques for image processing.

4.3.1 Design Visual and Description

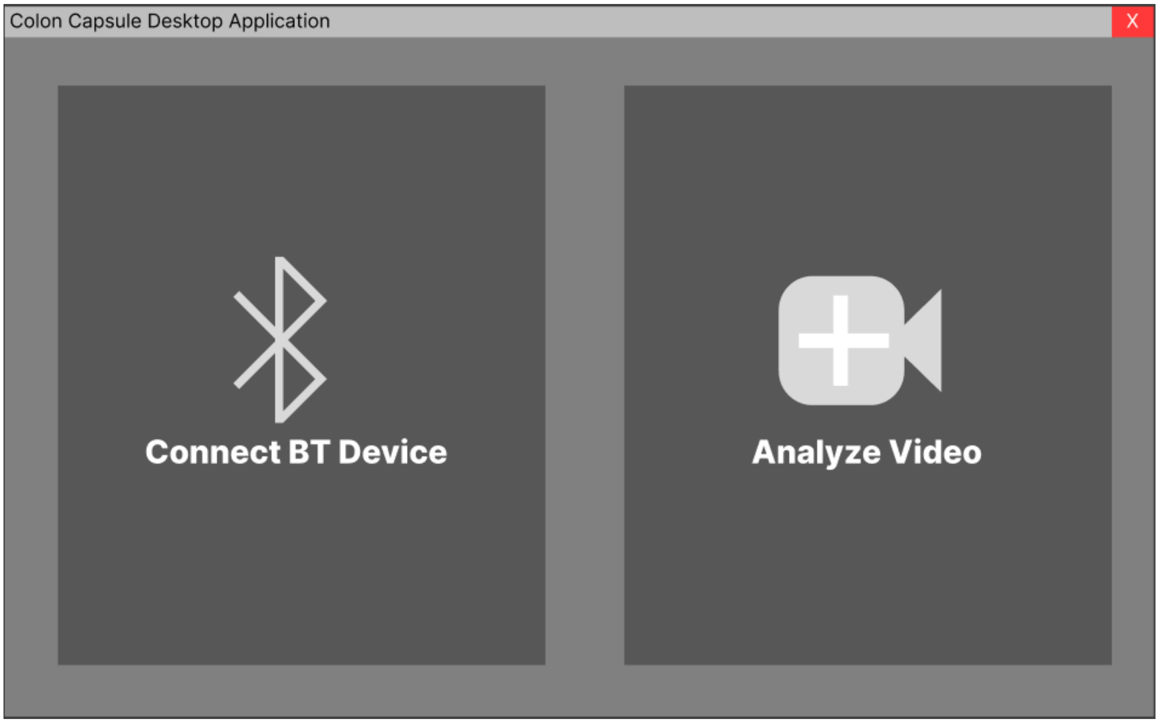


Figure 5 - GUI Main Menu

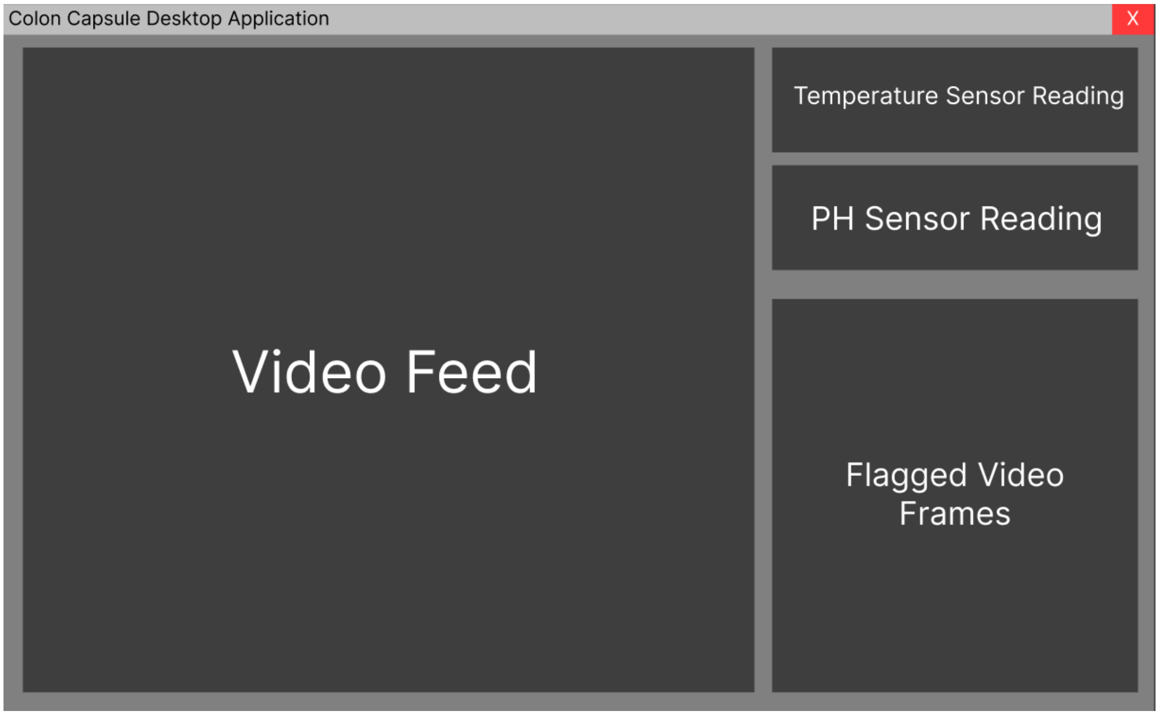


Figure 6 - GUI Main Layout

In Figure 5 we have an example of what our final desktop application landing page looks like. On the left-hand side is an option to connect the capsule via Bluetooth to enable a live feed straight from the capsule. On the right-hand side is the option to analyze a previously recorded video using the image processing software to detect video frames that may contain signs of colon issues.

In Figure 6 we have an example of what our final desktop application design may look like. On the left-hand side, we have the video feed from the capsule while, on the right-hand side, we have sensor readings and flagged video frames. In the flagged video frames section, we will show thumbnails of video frames that the image processing has detected something in for the user to manually review and mark.

4.3.2 Functionality

Our design for the desktop application is intended to operate by either first linking to the capsule via Bluetooth or allowing the user to drag a video or image folder into the application for image processing. Once the devices have been linked, it will show a live feed from the camera as well as sensor readings while also storing this data in files. These windows can then be rearranged around the application as the user intends. Our current design does not satisfy these requirements as we have been working on first implementing the image processing prior to developing the desktop application.

4.3.3 Areas of Concern and Development

One primary concern about the desktop application is that there is a chance that we may be unable to transmit Bluetooth data from the capsule directly to the desktop application due to range limitations. If we run into this issue, we would have to implement an in-between device to send data between the capsule and computer to increase the range.

4.4 Technology Considerations

The biggest strengths of existing capsules are the compact size and the advanced hardware. One downside of this choice is the steep price for small components.

4.5 Security Concerns

Security is a big issue when it comes to this project as we need to ensure that we are operating within HIPAA guidelines and ensure that no data about someone's health is seen by anyone besides the gastroenterologist as well as ensuring the project is safe for the patient.

4.5.1 Physical Security

One issue with physical security is ensuring that the capsule is safe for human consumption. This means that the capsule needs to be able to withstand the digestive system and gastrointestinal tract without being damaged or losing any components. Any damage to the system could be potentially harmful to the patient, so we must ensure that the system is sturdy and able to withstand damage.

4.5.2 Cyber Security

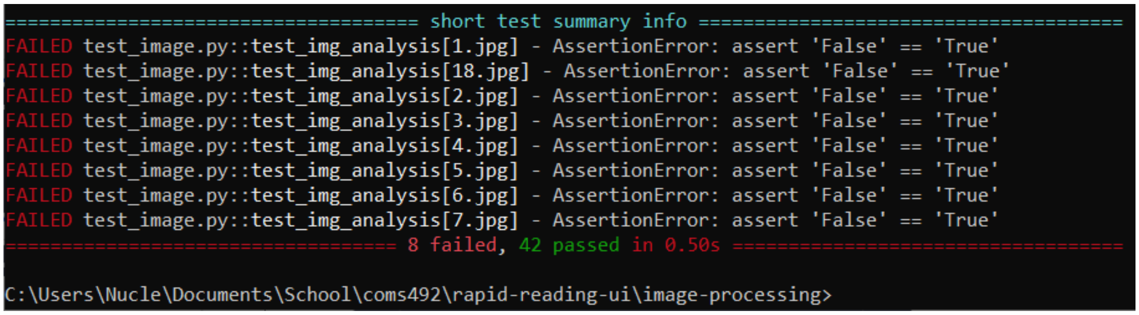
In terms of cyber security, we must make sure that nobody besides the gastroenterologist is able to connect to the Bluetooth capsule. We also must ensure that the images being analyzed are not sent anywhere besides directly to the computer. This means that we cannot utilize cloud-based computing for the image analysis.

4.5.3 Countermeasures

To properly account for the security concerns, we must ensure that the capsule has thick plating to make sure that it does not dissolve or become damaged within the patient. This means potentially utilizing even smaller components as it would technically need to fit inside of a 00-size capsule with the extra thickness bringing the size to 000.

We must also ensure that the Bluetooth capsule is only able to pair with the gastroenterologist's computer and nobody else's. This means that pairing needs to take place prior to the capsule being ingested and the connection should be confirmed on both devices before it is allowed to send image data. Ideally the gastroenterologist would also be directed to test the device to ensure image data is properly coming through before giving the capsule to the patient.

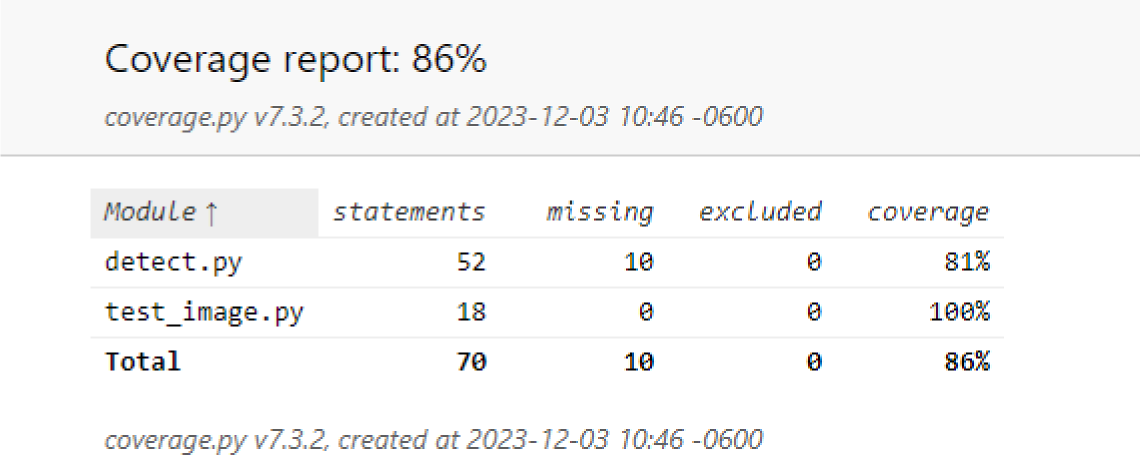
5 Testing



```
===================================== short test summary info =====================================
FAILED test_image.py::test_img_analysis[1.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[18.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[2.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[3.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[4.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[5.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[6.jpg] - AssertionError: assert 'False' == 'True'
FAILED test_image.py::test_img_analysis[7.jpg] - AssertionError: assert 'False' == 'True'
=================================== 8 failed, 42 passed in 0.50s ===================================

C:\Users\Nucle\Documents\School\coms492\rapid-reading-ui\image-processing>
```

Figure 7 - Unit Testing results for detect.py



Coverage report: 86%

coverage.py v7.3.2, created at 2023-12-03 10:46 -0600

Module ↑	statements	missing	excluded	coverage
detect.py	52	10	0	81%
test_image.py	18	0	0	100%
Total	**70**	**10**	**0**	**86%**

coverage.py v7.3.2, created at 2023-12-03 10:46 -0600

Figure 8 - Coverage report for the detect.py unit tests

5.1 Unit Testing

Our main testing method is doing Unit Testing with PyTest for our Python scripts. We run tests on each main functionality multiple times using different input values to make sure that the scripts work for multiple scenarios. We run twenty-five different tests for each functionality, Bluetooth communication, image analysis, and image saving. For image analysis, we supply the script with twenty-five different images from within the colon and a list of the expected result from the analysis should be. Once it finishes analyzing the images we check if the output is the same as the expected result. For image saving, we supply the script with twenty-five images to save and check to make sure each image is contoured then saved. For Bluetooth communication, we connect the script to the Bluetooth capsule, then send data back and forth counting and check if any communications were missed.

Before pushing any code to the Git repository, the developer should run these tests using the pytest command and check the results. If the results for the image saving or Bluetooth communication are below 90%, the code should not be pushed.

5.2 Future Tests

Unfortunately, we were unable to fully implement all the testing that we were hoping to implement this semester. However, we do have a plan for testing that we would like to add in the future. These tests would help ensure that no new changes would break old functionality and improve the codebase a lot. First, we would love to implement automated testing to help ensure that tests are run every time that new code is pushed which would help keep developers from forgetting to test their code. Next, we would focus on setting up different stages of testing rather than just focusing on unit testing.

5.2.1 Interface Testing

Interface testing will be introduced for the GUI to ensure that it displays properly on different devices. It will make sure that images properly appear in all locations that they are supposed to be able to be displayed and that the sampling rate input works as planned. Tests will also be run to ensure that the sizing of components and spacing between them is working properly.

5.2.2 Integration Testing

Integration testing will be introduced to ensure that the image analysis and Bluetooth Python scripts properly connect to the GUI. We will run tests to check whether image location data is properly passed between the Bluetooth script and the GUI, whether scripts are actually started consistently, and check data that is passed through the arguments to the Python scripts.

5.2.3 System Testing

System testing will be done using the Bluetooth capsule to ensure that data is properly sent from the capsule to the desktop GUI. It will then check that these images end up being stored if they are flagged. We will pre-load the Bluetooth capsule, with images from the database of GI images to test that the system actually detects things within the colon when they are sent from the capsule.

5.2.4 Regression Testing

Each new addition to the project will have its own test cases created to ensure the new feature functions properly. Once each addition has been successfully tested, these tests will be added to our regression testing process to ensure no previous additions will fail to work properly. This means that our regression testing process will grow as the project progresses but will help to ensure that every aspect of the project functions properly.

5.2.5 Acceptance Testing

Stability Testing

The final system test will be reconducted, except the capsule will be placed in chemicals that simulate various gut internals.

Animal Testing

Once all testing has proved successful, the capsule will be submitted for animal testing, and all biomedical tests required beforehand.

6 Implementation

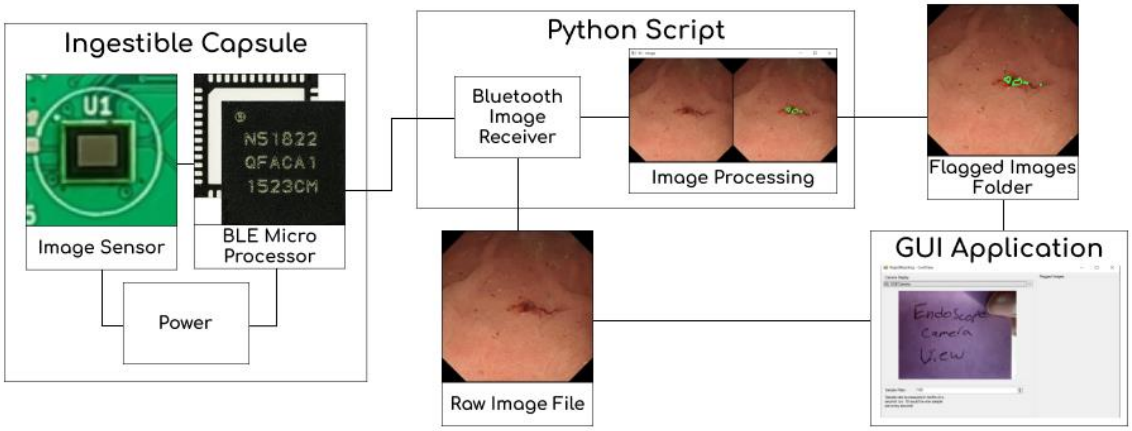


Figure 9 - Implementation diagram showing how the different aspects of the implementation connect together.

6.1 Image Processing

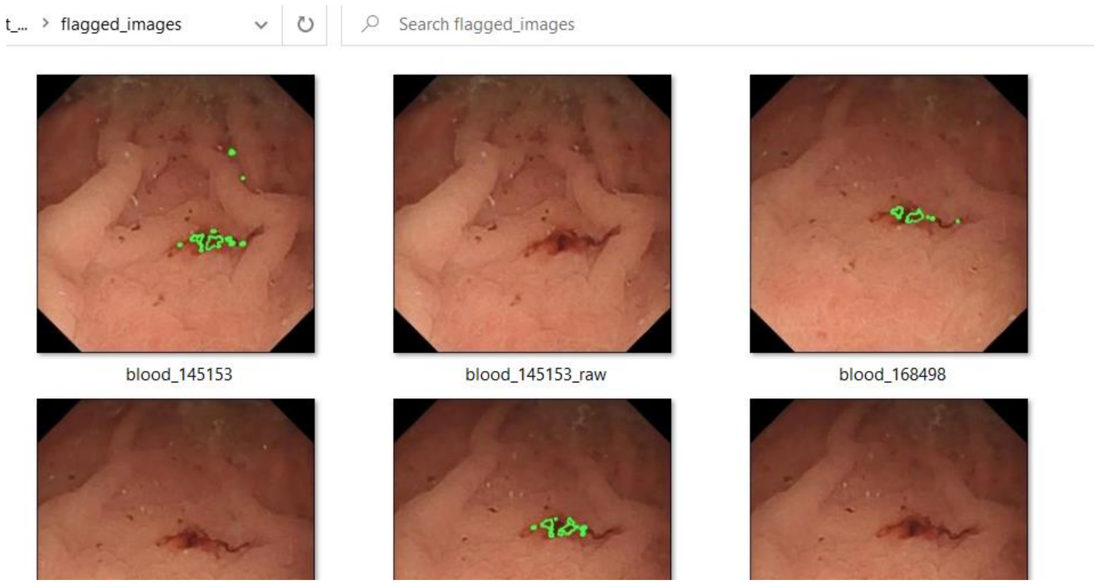


Figure 10 - An example of flagged_images after a directory scan was run using detect.py

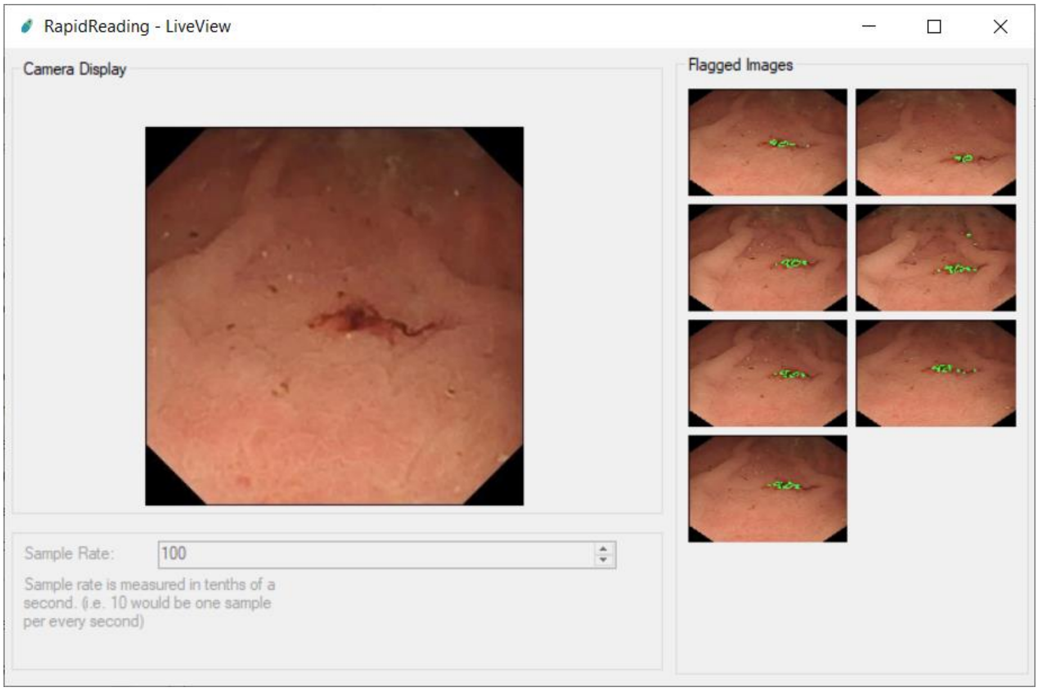
The implementation of image processing within this project was done utilizing Python scripts. The libraries utilized for these scripts were OpenCV, NumPy, Sockets, and ArgParse. The use of OpenCV was decided upon because our development team has had previous experience with the library and was most comfortable using it for our image analysis. It also has a variety of tools that can make image processing and analysis easier. The sockets library was used for connecting the Bluetooth capsule to the computer to send image data to the user interface. We broke our image implementation up into two Python scripts, one for the image analysis and one for the Bluetooth connection.

The Bluetooth script, which was saved under the filename “image_client.py”, was used solely for receiving images from the Bluetooth capsule and saving those images in a location that the user interface and image analysis script could access. Due to how many different parts of the software need access to the image and how our scripts are being run from the user interface, we decided to simply save the image being received as file within the application directory. The issue with this solution is that the Bluetooth script is unable to save another file if another program was already accessing it such as the user interface. To fix this, we implemented a buffer system where the file would be saved under one of two files, if one file is currently being accessed, we save the image received under the other file, and swap back and forth with the user interface on who is accessing which file.

The image analysis script, which was saved under the filename “detect.py”, was used to detect ailments within the images or directories passed to it from the command line. To differentiate between a single image analysis and a directory analysis, we used ArgParse to pass in a command argument—the command could be either “directory-scan” or “image-scan”—followed by the location of the image/directory. Once the script parses the arguments passed to it, it loads the image into memory, then uses various methods such as color contrast and shape analysis to check if an ailment is present. Once the script finds something present in the image, it checks it against a threshold, and if the value is higher than the threshold it saves the image under the "flagged_images" directory with a label stating what it found followed by a randomly generated number, for example "blood_103842.jpg".

The reason that our implementation splits the Bluetooth script and image analysis script in two is due to how we utilize these scripts within our user interface. The way the user interface accesses these scripts means that it calls the script and gives them certain arguments from the command line. Since we allow the user to analyze images in multiple ways—Bluetooth capsule, USB camera, and directory analysis—the Bluetooth script could have been combined with the Analysis script, but it would have made it much more complicated to edit and understand.

6.2 User Interface



Sample Rate: 100

Sample rate is measured in tenths of a second. (i.e. 10 would be one sample per every second)

Figure 11 - The GUI in Bluetooth mode with an example of flagged images and input from a simulated GI tract

The implementation for the user interface mainly utilizes C# and WinForms to create a graphical user interface (GUI) for the user to either monitor the camera within the gastrointestinal tract or select a directory to be analyzed. The GUI opens to a menu that has three options presents, one for using a USB camera, one for connecting to the Bluetooth device, and one for analyzing a directory.

For the USB camera, the GUI runs on a continuous loop using a background thread for the camera operations and image analysis. The background thread starts by getting the image data from the camera and storing it. From there it will display this image to the user so that they can keep track of where the camera is within the colon, then it will save that image to the hard drive so the doctor can keep track of it later before starting the image analysis script and giving it the argument "image-scan" and the location of the image. Once the image analysis script terminates, the flagged images UI is updated to show if any new images had ailments detected within them. This loop then repeats for the entirety that the GUI is open.

For the Bluetooth capsule setting, the general functionality is very similar, however instead of one background thread, two background threads are needed to ensure proper functionality. One of the threads that is run continuously is the Bluetooth thread, which starts the “image_client.py” script and keeps track of running it for the whole time that the GUI is open. Once an image is received, the image analysis thread will retrieve the image from where the Bluetooth thread saved it, then start the “detect.py” script to analyze the image. Once this script terminates, both the flagged images and camera view UI will update to show any newly flagged images and the current image received from the camera.

For the directory analysis, once the user selects the directory where the images are located, the program will grab the directory string from a directory selection popup and begin a process for the image analysis script. When starting the image analysis script, the GUI will send it two arguments, one argument being the string “directory-scan” and the other giving a string for the directory the user selected. Once the directory has been completely scanned, the script will terminate, and the GUI will open the flagged images in File Explorer.

This is one of the reasons that we split the image processing into two scripts because the Bluetooth script will need to run continuously in its own thread for the entire time that the GUI is opened, but the image analysis script only needs to run whenever an image or directory needs to be analyzed, then it can be terminated, and the GUI can keep running.

6.3 Bluetooth Capsule

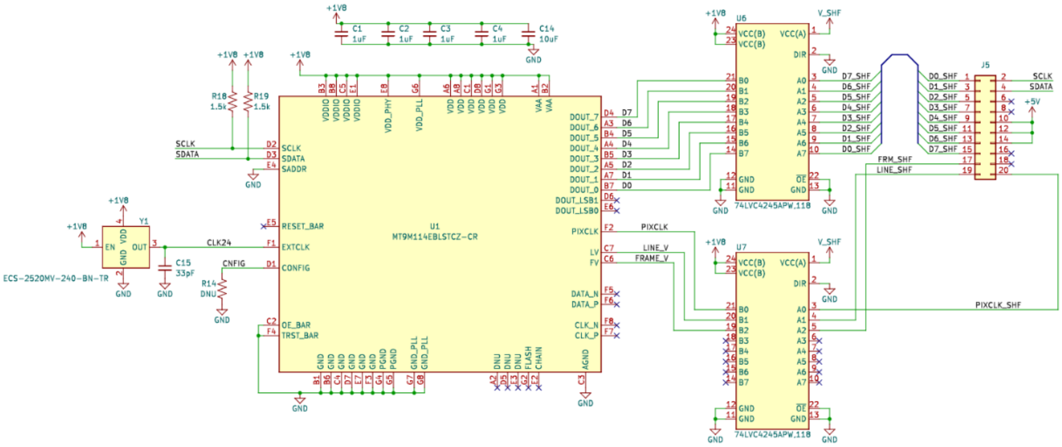


Figure 12 - The final circuit design for the Bluetooth capsule

During our initial research concerning the schematic of the Bluetooth capsule it was quickly decided that the image sensor was the critical component. Due to our application, the criteria for this sensor were very lax; our projected framerate was closer to one per minute rather than many per second. Unfortunately, all commercially available image sensors that would be able to physically fit into the capsule size requirements were significantly more complicated than our project required. Ultimately, the MT9M114 was selected based on its physical size and price with nearly all other options not meeting the size requirement.

After choosing the MT9M114, the next main decision was choosing the output data format. The options were a “default” 8-bit (or 10-bit) parallel pixel output or a MIPI (mobile industry processor interface) serial output. In hindsight, the decision should have been almost immediate- for the MIPI port to sustain the advertised 30/60 fps framerate, the absolute minimum clock speed required would be 250 MHz compared to the 96 MHz output from the parallel port. While the latter can be handled with some microcontrollers, the former almost certainly requires an FPGA to interface with the image sensor and handle the MIPI “decoding.” A 250 MHz output is also fast enough to warrant signal integrity concerns that are normally irrelevant when designing a slow-speed PCB.

Our team ended up choosing the 8-bit parallel output due to the simplicity of image output implementation: each pixel could be stored as a uint8_t variable as part of a long 2-dimensional image array that could be directly transmitted over Bluetooth as a long string. This implementation directly bypasses the difficulties of working with images over Bluetooth as the transmission would just be a long string of bytes. Framerate is also not an issue, so it is fine to store one frame at a time and simply ignore outputs from the image sensor until the Bluetooth microcontroller is ready to send another frame.

Once these decisions had been made, the schematic design was very straightforward. The image sensor was set up according to the datasheet as shown in the image below. Minor changes made because only one device was used, SADDR was pulled low, RESET_BAR and CONFIG could be left floating due to an internal pullup, the MIPI serial port was left floating/unused. One minor complication was that most microcontroller development kits use 5V or 3.3V logic, while the image sensor uses 1.8V. This was worked around by adding level shifters between the parallel port and the data breakouts as well as adding a dedicated 1.8V switching regulator for everything on the test PCB.

7 Professionalism

7.1 Areas of Responsibility

Table 1. The seven areas of professional responsibility in the assessment instrument

Area of responsibility	Definition	NSPE Canon	IEEE Canon
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence	Perform services only in areas of their competence; Avoid deceptive acts	Only perform tasks for others if properly trained or experienced; Improve technical competence
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs	Act for each employer or client as faithful agents or trustees	Always reject bribery of any form

Communication Honesty	Report works truthfully, without deception, and understandable to stakeholders	Issue public statements only in an objective and truthful manner; Avoid deceptive acts	Be honest and realistic when claiming or estimating
Health, Safety, Well-Being	Minimize risks to safety, health, and well-being of stakeholders	Hold paramount the safety, health, and welfare of the public	Be responsible for making decisions that align with health, safety, and welfare of the public or environment; Promptly disclose factors that might endanger either
Property Ownership	Respect property, ideas, and information of clients and others	Act for each employer or client as faithful agents or trustees	Avoid damaging others, their property, or their reputation
Sustainability	Protect environment and natural resources locally and globally		Disclose factors that might damage the environment
Social Responsibility	Produce products and services that benefit society and communities	Conduct themselves honorably, responsibly, ethically, and lawfully to enhance the honor, reputation, and usefulness of the profession	Improve our understanding of technology and its potential consequences; Do so while supporting colleagues and coworkers and avoiding any conflicts of interest

Figure 13 - Area of Responsibility Table

Differences:

Work Competence - IEEE differs mainly in trying to improve technical competence in addition to NSPEs standards.

Financial Responsibility - NSPEs can apply to more than just bribery in terms of financial responsibility, but IEEEs seem to be more specific in terms of bribery.

Communication Honesty - Both are very similar. They both require the engineer to be honest, but IEEEs also require a degree of realism in addition to honesty, so an engineer does not mislead further.

Health, Safety, Well-Being - Here, IEEEs focus more on the decision-making aspect of this, but both focus on protecting others' health and safety.

Property Ownership - These are very different. For NSPEs their standard is acting as a faithful agent. This can mean a lot of different things, but ultimately being responsible for the client. IEEEs focus more on property damage and damage to reputation. Making sure that these things do not happen.

Sustainability - There does not seem to be much in terms of sustainability in NSPEs canons. IEEE is very different in the fact that they state they should disclose factors relating to environmental concerns.

Social Responsibility - Both of these are similar. The only way that these differ is in how NSPEs are more generic about honor while IEEEs focus more on improving technological understanding.

7.2 Project Specific Professional Responsibility Areas

For each of the professional responsibility areas in Table 1, discuss whether it applies in your project's professional context. Why yes or why not? How well is your team performing (High, Medium, Low, N/A) in each of the seven areas of professional responsibility, again in the context of your project. Justify.

Work Competence - Yes this does apply to us, but it applies to us more in terms of improving technical competence than the rest of it. This is because we need to learn more about Bluetooth capsules and rapid reading which is something I am pretty sure most of us have minimal experience in. The experience we have gained through our other classes would be useful here.

Financial Responsibility - No or unlikely. While this makes sense to do in most engineering professions, this project is a more controlled environment with little opportunity for bribery. If it does occur, we should be able to spot when this happens.

Communication Honesty - Yes. This is important for us because when we need to communicate pieces of information, we need to make sure that our expectations are accurate. If we set a time frame or budget, we need to do so to the best of our knowledge.

Health, Safety, and Well-Being - Yes. While it would be impossible in this project to do human trials, we need to keep in mind the "end goal" if the project were to be launched is to diagnose issues humans may be having. With this in mind, we must keep clients' health and safety in mind.

Property Ownership - No. This is unimportant in our case because we will only be dealing with property we control and since the scale is so small there is a negligible likelihood of damaging much else.

Sustainability - No. Since this is a small-scale project, we do not need to worry about the damage to the environment much if at all.

Social Responsibility - Yes. We need to make sure that we learn about the technology we are working with thoroughly during this project. We also need to make sure that our teammates and others know enough to do the same.

7.3 Most Applicable Professional Responsibility Area

Communication honesty - Our team thus far has done a good job of communicating honestly with each other. Going forwards, it will be important that all parts of the project are able to mix well. If actions need to be taken for the project to move forward smoothly, it is important that these actions are communicated within the team as to not create bottlenecks. So far, we have demonstrated a fair amount of responsibility for communication, especially since we have been unable to schedule a second meeting with the professor. This means that even though we are currently at a bottleneck, other work is being done that is not affected by the bottleneck, and we are hard at work making a new schedule to accommodate the professor.

8 Closing Material

8.1 Discussion

The current result of our project is mostly knowledge gained by the team. We have yet to make much physical progress on our project in terms of creating a functional circuit or image processing algorithm. We have created base designs for our software layout, have an idea of components for the circuitry, and have constraints and plans for the image processing. This progress, while mostly relating to a plan for moving forward, is still helpful in achieving our end goals.

8.2 Conclusion

So far, we have made substantial progress learning about already available capsules and finding components that will fit our project. We have also made progress researching image processing algorithms and planning out our method of developing our own image processing algorithm. Our goals for this project are to create an ingestible capsule that can monitor pH and temperature and stream a live video feed to a separate computer that will analyze the video feed using image processing. Currently, we have been unable to produce a physical capsule that successfully implements these sensors and have yet to create software to analyze the video feed. We are still making progress towards these goals but better planning and time management from all on the team would have allowed us to make progress towards these goals much faster. We still hope to be able to complete these goals by the end of next semester as we are still on track with our current schedule.

8.3 References

[1] P. H. Smedsrud et al., “Kvasir-Capsule, a video capsule endoscopy dataset,” Scientific Data, vol. 8, no. 1, May 2021, doi: https://doi.org/10.1038/s41597-021-00920-z.

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[3] U. Kalwa, C. Legner, T. Kong, and S. Pandey, “Skin Cancer Diagnostics with an All-Inclusive Smartphone Application,” Symmetry, vol. 11, no. 6, p. 790, Jun. 2019, doi: https://doi.org/10.3390/sym11060790.

[4] H. Borgli et al., “HyperKvasir, a comprehensive multi-class image and video dataset for gastrointestinal endoscopy,” Scientific Data, vol. 7, no. 1, Aug. 2020, doi: https://doi.org/10.1038/s41597-020-00622-y.

9 Appendices

9.1 Operation Manual

To build and run the user interface for this project, you will also need to follow the instructions to build and run the image processing scripts. This is due to the user interface relying on the scripts to run properly, meaning that the scripts need to be able to have all dependencies that they rely upon.

If you do not need to use the graphical user interface and would prefer to just run the program through the command line, simply follow the instructions in 9.1.1 Image Processing Scripts and skip the user interface instructions.

9.1.1 Image Processing Scripts

Before you will be able to properly run the image processing you must first make sure you have Python installed, you can install it from here. After installing Python you must make sure you have pip installed, to install pip follow these instructions.

Once pip is installed you must install OpenCV, to do this simply type the following command in the command prompt.

```
pip install opencv-python
```

Once that command has finished you can navigate to the script directory and run the script using the following command.

```
py detect.py
```

9.1.2 User Interface

Before you can build and run the user interface, you must make sure to install the proper dependencies through NuGet in VisualStudio.

On VisualStudio 2017 and above, you can simply click the Search bar at the top of the window and type in "NuGet". You will see a list of results pop up, select the option that says "Manage NuGet Packages..."

This should open a window for managing NuGet packages. By default, this window will open to the Installed tab and show you packages that you already have installed. Select the tab in the top left of this window that says Browse and type "OpenCvSharp" into the search bar.

The Packages Needed are as Follows:

- OpenCvSharp4
- OpenCvSharp4.Extensions
- OpenCvSharp4.runtime.win

If these packages are already listed as installed, you will need to uninstall them and reinstall them to update the project.

After you finish installing the packages, you must make sure that 'detect.py' and 'image_client.py' are in the bin directory. Navigate to UI/RapidReading/bin/Debug or UI/RapidReading/bin/Release depending on which build you select and place 'detect.py' and 'image_client.py' in that directory if it is not already present.

After following these steps, you should be able to simply select the build button in VisualStudio and the project will run correctly. After the project has been built once, to run the project you can simply use the executable file that is present within the build directory to run the project without rebuilding it.

9.1.3 Testing

First you must install pytest using pip, use the following command to do so.

```
pip install pytest
```

After installing pytest, simply type 'pytest' in the image-processing directory to run the tests.

9.2 Project Evolution

The project design has stayed relatively the same since the end of 491. A lot of the changes that came about for the design were internal decisions such as how to implement the image analysis and Bluetooth. Originally in our designs we expected to have the GUI be programmed using C# and the image analysis and Bluetooth retrieving scripts as Python just as our final product had. However, we originally had planned for the script that receives images via Bluetooth to be the same script as the image analysis script. In the end, this design had to change because we realized that the receiving of images should be done on a separate thread from the image processing.

We also had to scrap a lot of the planned automated testing through CI/CD pipelines simply because we did not have enough time to fully implement them without sacrificing the quality of our final product. We do still plan on implementing this in the future, however, we were unable to accomplish it before the end of 492.

Many of the changes in design came from the hardware perspective. Originally, we had planned to make use of pH and temperature sensors within the capsule to provide more information to the gastroenterologists. This idea was scrapped, however, as our client wanted us to focus more on the camera data and image analysis portion of the project. This meant our design changed a lot on the hardware side, as we only had to implement an image sensor without the two other sensors. This also changed the software side of things as we no longer had to include a way to receive this data on the desktop and also did not have to display it to the user.

9.3 Team Contract

Team Name: Bluetooth-Enabled Ingestible Capsule to Monitor Gut Activity (sddec23-19)
Team Members: Chase Thompson, Cutler Thayer, Jon “Tucker” Thomas, Robert Zukowski

Team Procedures:

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

Regular team meetings will be decided by our workload and a calendar with team-member availabilities plotted on it. Meetings will be face-to-face or virtual depending on team member availability and may be cancelled for uneventful weeks or ones where group members meet a lot due to higher workload. At the moment, the best meeting time for the group would be Friday or Sunday afternoon.

2. Preferred method of communication updates, reminders, issues, and scheduling:

The group has a discord chat set up to discuss the above. Scheduling will be done case-by-case, but any contact with the professor (or associated graduate students) will be done through an email chain.

3. Decision-making policy:

Majority vote tends to ignore ideas that can seem fruitful and end up working out or, more dangerously, great sounding ideas that waste time. Everyone should feel as though they have a place in the group decisions and processes. To address this, ideas will require a 100% team approval after discussion. Any ideas not agreed on can be worked on individually without affecting the group’s overall time to gain more data. Group members are trusted to be mature enough to recognize that ideas can turn out badly and sometimes should be given up on in favor of something more agreeable.

4. Procedures for record keeping:

Team members will be trusted to give an estimate of their own time spent on the project; forward progress is significantly more important than spending time on something. In addition, making one team member focus on keeping track of others time will only slow down their own additions as opposed to making others more efficient.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:

Team members are expected to be punctual at meetings and show up to all on time. However, it is also understood that each team member is an adult that has other time commitments. In such events, notice should be given to other team members that an individual cannot be present or will be late. Should this begin to occur more than other team members are comfortable with, a team discussion will be called to figure out solutions for these tardies/absences.

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:

As previously stated, individual responsibility is paramount to produce on-time submissions. Due to the importance of deadlines compared to meetings however, more notice should be given if any doubt is had as to the availability of a group member. This notice cannot be set in stone due to different assignments taking longer or shorter amounts of time to complete, and as such is up to the discretion of teammates to discuss when such a problem arises.

3. Expected level of communication with other team members:

Punctual communication is expected. Team members should be in contact asap, but without interference in other coursework or responsibilities. Should a team member have outside responsibilities that prevent them from being in contact to a significant degree, this should be mentioned to other members so nobody is expecting them to be on call when they cannot be.

4. Expected level of commitment to team decisions and tasks:

Once an important decision has been made, as per voting policy all team members should be on board 100%. If a mindset changes, it can be brought up with the team again. Team members are expected to understand that even if they don’t like an idea, sometimes trying something is better than staying in the brainstorming process.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

The leader of the project is the professor. Apart from that, team members should be confident enough to give direction in their area of expertise.

2. Strategies for supporting and guiding the work of all team members:

Team members should be able to do the tasks designated to them, however, should they encounter difficulties it is expected that they reach out to the rest of the team and either receive help from another team member or designate the task to someone else.

3. Strategies for recognizing the contributions of all team members:

Team members will log their contributions and progress. If people are contributing, it will have tangible evidence.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

Chase Thompson: I have previously worked with embedded systems, PCB design, and software extensively. My skills will mostly be applied in working with software/AI for the capsule and the application for this project.

Cutler Thayer: I have an interest in things both hardware and software related. While I do lean in any particular direction, I have enough knowledge in both that I can help on either side when necessary.

Tucker Thomas: I have a unique interest in building hardware. I’m confident in my ability to design and build circuits that contain complex logic structures.

Robert Zukowski: Electrical Engineer of the high frequency variety. Most likely to contribute to any Bluetooth, antenna, or communication related project sections. Also, I have considerable experience with PCB design and manufacturing as well as a strong coding background.

2. Strategies for encouraging and support contributions and ideas from all team members:

In any brainstorming process, it is important to hear all ideas and not throw anything out immediately. Even if it is a bad idea, it might inspire better ones later. Creativity is incredibly hard, and we will all be grateful if anyone displays it well. Independent and collaborative brainstorming is beneficial for all group members, and it is highly encouraged.

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

Team members should feel comfortable messaging the group as a whole. If this is not the case, contacting any individual member, TA, or professor should be encouraged. A team works best when they are all happy and welcome in the group. If the team cannot spend time together informally without feeling uncomfortable, this should be a sign that one or more members may be losing motivation.

Goal setting, Planning, and Execution

1. Team goals for this semester:

- Determine an overall goal regarding the prototype.
- Create a digestible capsule with all required sensors.
- Create a connection between the capsule and an external interface.
- Create a GUI that takes in the raw data from the sensors and makes it understandable.

2. Strategies for planning and assigning individual and teamwork:

In team meetings, we can discuss what member(s) will be the best fit for what part of the current thing that needs to be done. If a member encounters an issue that needs to be solved in the part they are working on, they can either do it individually or bring it up to the team and delegate responsibilities.

3. Strategies for keeping on task:

- Take care of your body; find ways to reduce stress while staying motivated and hardworking.
- Be expressive of your ideas and feelings regarding the project.
- Stay creative and mindful.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?

Minor infractions are ok. We are all adults and sometimes things happen. Should infractions continue to build up with no effort being made by a group member or in the case of significant infractions, the team will determine a meeting date where everyone (especially the problem member) is available and discuss options.

2. What will your team do if the infractions continue?

Should issues get out of hand, the professor or senior design teachers are always available to discuss more heavy-handed solutions.

Signatures:
a) I participated in formulating the standards, roles, and procedures as stated in this contract.
b) I understand that I am obligated to abide by these terms and conditions.
c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) Robert Zukowski **DATE:** 02/19/2023
2) Tucker Thomas **DATE:** 02/19/2023
3) Cutler Thayer **DATE:** 02/19/2023
4) Chase Thompson **DATE:** 02/19/2023