**Project Title**

The Carleton Eye

Supervisor: Dr. Yvan Labiche

Group members:

|  |  |  |
| --- | --- | --- |
| **Student name** | **Student number** | **Course** |
| Chukwuka Ihedimbu | 101081703 | Computer Engineering |
| Ruona Osharode | 101081815 | Communications Engineering |
| Oluwaseyi Sehinde-Ibini | 101092822 | Computer Engineering |

Table of Contents

[1. Introduction 4](#_Toc96728750)

[1.1. Background 4](#_Toc96728751)

[2. Aim and Objectives 5](#_Toc96728752)

[3. Requirements 6](#_Toc96728753)

[3.1. Functional requirements 6](#_Toc96728754)

[3.2. Non-functional requirements 6](#_Toc96728755)

[4. Significance of work 9](#_Toc96728756)

[5. Methodology 10](#_Toc96728757)

[5.1. Project timeline 10](#_Toc96728758)

[5.2. Group members and responsibilities 10](#_Toc96728759)

[5.3. Safety and precautions 11](#_Toc96728760)

[5.3.1. Possible project risks 11](#_Toc96728761)

[5.3.2. Precautions 11](#_Toc96728762)

[6. System Architecture 12](#_Toc96728763)

[6.1. Sub-systems and non-functional requirements 12](#_Toc96728764)

[6.2. Justification 14](#_Toc96728766)

[6.2.1. Link and communication 14](#_Toc96728767)

[To conclude, from all these communication technologies, the best that would help us achieve the most NFRs is the 2.4Ghz RF chip named “Synapse RF266PC1”, this option has the longest possible distance and a reasonably large enough throughput to match. 15](#_Toc96728768)

[6.2.2. Signal Loss and Interference 15](#_Toc96728770)

[6.2.3. The Video capture system 16](#_Toc96728771)

[6.2.4. The SWall 18](#_Toc96728774)

[6.3. Verification 18](#_Toc96728775)

[6.3.1. Link and communication 18](#_Toc96728776)

[6.3.2. The Video capture system 20](#_Toc96728777)

[6.3.3. SWall 20](#_Toc96728778)

[6.4. Conclusion 21](#_Toc96728780)

[6.4.1. Hardware Components Diagram 22](#_Toc96728781)

[6.4.2. Software Components Diagram 22](#_Toc96728782)

[7. Reference 24](#_Toc96728783)

# Introduction

## Background

The SWall is an interactive computer system with up to four slave computers, each with one large touch screen, and a master computer that manages the communication and flow of data between the slave computers. With the presence of a large screen and Microsoft Kinect, the SWall can be used for a number of entertaining activities such as watching videos, animations, games and other interactive applications.

After a few interactions with the SWall it was observed that there are very few interactive applications on the SWall, such as the Carleton 3D model view application and a Virtual Reality application. This project called “The Carleton Eye” is a technical feasibility project that aim to improve students’ experience with the SWall by adding a new level of user experience to the SWall. The Carleton eye would enable students view a live feed of a surveillance camera on a drone and enjoy the view from the highest point in the university.

This project will assess the different possible approaches to capture and stream live video footage from a very high location in the school with a drone being controlled from the SWall.

# Aim and Objectives

The primary goal of this project is to build an autonomous surveillance camera system with remote control feature and live feed available on the SWall.

The following are the objectives:

1. The system should capture and stream live video footage from a drone to the SWall.

2. A user should be able to control the drone and view the field of the camera system from the SWall.

# Requirements

The requirement needed for this project shall be categorized into functional and non-functional requirements. The functional requirements define the system of our interest, while the non-functional requirements define the quality and metric attribute considered or required to achieve our desired system functionalities.

The Carleton eye would need the following requirements to fulfill its aim.

## Functional requirements

1. The system shall capture videos and stream it to the SWall.
2. The SWall shall render the streamed video on its display.
3. The SWall will provide different control mechanisms (keyboard, joystick, touchscreen and gestures) to control and observe different angles of the view of interest.
4. The system shall stabilize unsteady video footage
5. The system shall have a night vision feature, to enable night surveillance.
6. The system should detect the presence of objects close to it and avoid collision with the objects. Collision with objects will cause different levels of damage to either the device or the object.
7. The system should have two modes of control, “safe/cruise mode” and “pro mode”, this is to enable individuals with little or no drone flying experience interact with the system, only properly trained drone pilots would be allowed to operate the system in “pro mode”. This is detailed more in NFR10 and NFR11.

## Non-functional requirements

The Non-functional requirement types used in this section are based on article [22]

SECURITY AND DATA INTEGRITY

* 1. Data encryption: The data captured should be encrypted with 256 AES encryption algorithm, this is to ensure high data integrity since AES is considered to be one of the most secure encryption algorithms [22].
  2. Data privacy and policy: Sensitive data and video captured should not be available for download on any platform, this is to conform with existing privacy policies regarding images and videos of private entities that may be captured within the location to be covered.

AVAILABILITY AND RELIABILITY

* 1. Availability: The system should be available for use at least 99% of the time. This is solely for user experience.
  2. Reliability: The system should respond appropriately to commands at least 95% of the time under good weather conditions, this is very important for good user experience.

PERFORMANCE

* 1. Response time: The system should respond to flight commands from the SWall in not more than 1100ms, this is because slower response to control will cause unwanted or catastrophic results in situations where split-second decision is needed.
  2. Video quality: Video captured should be in at least 1k resolution. Lesser video quality would not be enjoyable for the user.

FLEXIBILITY

* 1. Range: The system should have a control range of at least 400 meters, this is to put into consideration the farthest distance from the location of the server to the location of interest, 400 meters is the estimated distance between these two points and the communication system should have a long enough range to send and receive data from these two points.
  2. User experience: Changing the view of focus should not require more than 2 clicks/touches/distinct movements, this is to ensure that the system is simple enough to be used by students and non-technical personnel.
  3. The “Pro mode” would have all possible drone control buttons, controls such as yaw, pitch, roll, and throttle. This mode would only be accessible by authorized personnel with a user login and password.
  4. The “Safe mode” should only provide gestures for controlling the drone, the drone should also be intelligent in this mode and not fly out of a predefined space.

SUPPORTABILITY

* 1. The system would rely on off-the-shelf components, this is to reduce development time and ensure components can be easily maintained and upgraded.
  2. The wireless communication technology of choice should comply with policies and regulations regarding wireless communication.
  3. The wireless communication technology of choice should not require excessive certification and licenses, this would reduce cost.
  4. The system shall be part 107.31 visual line of sight aircraft operation compliant, as to fly beyond visual line of sight (BLVOS).

# Significance of work

The project is useful in the following ways:

1. Improve the students understanding of communication protocols and video compression algorithms. As students in computer engineering with focus on communication technologies, this project would contribute to the knowledge and experience requirement needed to design and implement a remote surveillance system.

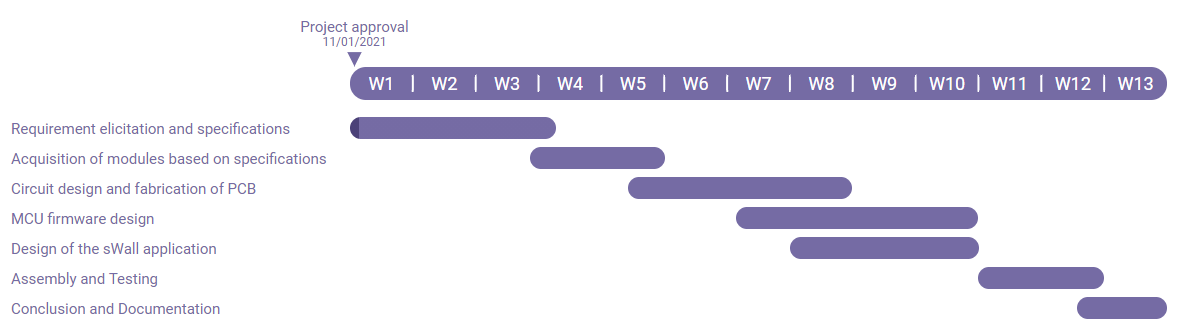
2. An interactive application to increase the level of engagement with the SWall.

3. It can be used by students in earth sciences for capturing and analyzing geographical images of specific locations in the school.

# Methodology

## Project timeline

Below is a Gantt chart that shows the tasks to be carried out in achieving the aim and objectives of this project and an estimated time duration each task would take starting from the point of project approval.



*Figure 1: Project Timeline*

## Group members and responsibilities

|  |  |  |
| --- | --- | --- |
| **Student name** | **Course** | **Roles and Responsibilities** |
| Chukwuka Ihedimbu | Computer Engineering | Hardware:   * Circuit design and fabrication. * System Architecture and Physical system assembly. * Eliciting of requirements |
| Ruona Osharode | Communications Engineering | The Microcontroller unit (MCU) firmware:   * Implementing the video compression algorithm on the MCU * Wireless communication protocol specification and implementation. |
| Oluwaseyi Sehinde-Ibini | Computer Engineering | SWall application :   * The design of the user interface and user experience on the SWall |

## Safety and precautions

### Possible project risks

There is a possibility of drone crash occurrence which could be due to inexperienced personnel controlling the drone, adverse weather conditions, unexpected system/module failure or complete power drain.

### Precautions

To prevent the risks from occurring, the following should be put into account:

1. We will strongly advise not to use the system under adverse weather conditions.

2. All modules would go through routine checks and tests in the lab and controlled spaces before being used in public.

3. Drone system would only fly with at least 30% of battery power and it would be programmed to make a safe landing when battery power is below 10%, even if it’s going to be against the user’s interest.

A list of special components that would be needed include:

1. Access to cellular network infrastructure

2. Drone flying permit

# System Architecture

This section outlines and illustrates the result of an analytical study carried out on the functional and non-functional requirements as well as the hardware and software design approach that best satisfy all the requirements.

### Components Diagram

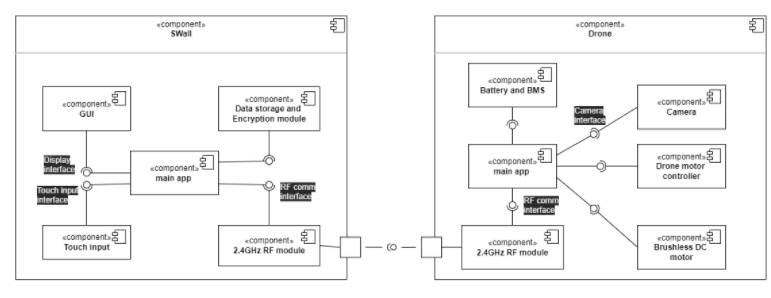


Figure 1: components diagram of system

The image above is the components diagram of the system, it shows the two hardware components that would run the user application, It also shows the different software modules and interfaces that would be created on these hardware devices in order to achieve the requirements of this project.

The RF comm interface for both devices are the same i.e., the 2.4ghz module would be preloaded with a firmware that enables it to simply take commands and packet via SPI to send over RF to the other node.

## Sub-systems/Interfaces and non-functional requirements

Below is a table that shows the non-functional requirements and which of the sub-systems or interface would be used to meet with these requirements, the interfaces mentioned here can be seen in Figure 6.1.

NB: Software components are suffixed with “interface” while the hardware components with “hardware subsystem”

|  |  |
| --- | --- |
| **Functional Requirement** | **Subsystem** |
| ‎FR1 | Camera interface and RF communication interface |
| FR2 | Display interface.  The GUI would contain a large view area like a video player interface that displays the streamed video from the drone |
| ‎FR3 | Touch Input interface.  The GUI software would be designed to provide touch areas and take touch inputs to be sent to the drone as commands |
| ‎FR4 | SWall main app and RPi main app  The received video footage would be run through a video stabilization algorithm on the SWall. The Main drone flight application would also be responsible with maintaining stable while capturing video footage |
| ‎FR5 | Camera interface  The drone camera would be fitted with camera with night vision |
| ‎FR6 | Proximity sensor interface  The drone would have distance sensors in order to detect the presence of large objects around and gradually move away from them |
| ‎FR7 | SWall main app.  The SWall GUI interface for this system will only enable swipe gesture in the “safe mode” and provide directional buttons and other control buttons in “pro mode” |

|  |  |
| --- | --- |
| **NF Requirement** | **Subsystem** |
| NFR1: Data encryption | RF communication interface  The AES encryption algorithm will be implemented on this module as to eliminate attack vulnerability and guarantee a secured communication system. |
| ‎NFR2: Data privacy and policy | SWall hardware subsystem  Sensitive video coverage of individuals or incidents shall be protected from public consumption. |
| ‎NFR3: Availability | SWall, Link & Communication and Drone subsystem  All the equipment, components and subsystems must be in a specified operable and committable state (99% reliable), for any use case at a random time. |
| ‎NFR4: Reliability | RF communication interface and RPi main app |
| ‎NFR5: Response time | RF communication interface  The interface shall ensure that the system is responsive and mustn’t exceed 1100ms before it processes flight commands. |
| ‎NFR6: Video quality | Camera interface and Camera hardware subsystem  Should be able to provide video streams in nothing less than 2k resolution. |
| ‎NFR8: Range | Link and Communication hardware subsystem  The desired control range is expected to be 400meters or greater, so the module should be able to cover that. |
| ‎NFR9: User experience | SWall main application and Display interface:  The SWall must not experience video glitches or lag, and must be responsive at all times. |
| ‎NFR10: Pro mode | Display interface |
| ‎NFR11: Safe mode | Display interface |
| NFR12: COTs | - |
| NFR13: Compliance | - |
| NFR14: Excessive certification | - |
| NFR15: 107.31 Visual line | - |

*Table 1: 1.1. Sub-System and NFRs*

## Justification

### Link and communication

Here we compare the individual communication technologies considering the number of NFRs they satisfy. Several wireless communications technologies exist in the market. They each have their pros and cons. The requirements of this project have been clearly stated and a decision would be drawn after extensive examination of the specifications of these wireless communication technologies.

We reviewed the characteristics of the following different communication technologies Bluetooth, 2.4Ghz RF, 433MHz RF, 4G/LTE and Wi-Fi. This choice of technologies is to satisfy NFR12 which obliges us to rely on off-the-shelve components.

|  |  |  |
| --- | --- | --- |
| TECHNOLOGY | RANGE (m) | THROUGHPUT (Kbps) |
| Bluetooth | 10 | 2000 |
| 433MHz | 40 | 9.6 |
| Wi-Fi | 150 | 54000 |
| 2.4Ghz RF Transceiver | 1200 | 250, 500, 1000 and 2000 |
| 4G/LTE | 16000 | 100000 |

*Table 2: List of wireless communication technology and their properties*

The above table shows the properties of five major wireless communication technologies. In the following paragraphs, we discuss these properties in detail and justify which of these technologies would be the best fit

**Wi-Fi communication technology**: This communication technology meets all the listed NFRs related to communications except NFR8 (Range). Our required range is 400m and above, unfortunately the Wi-Fi communication technology transmission range is about 150m. This nullifies its usefulness for our required project as it cannot achieve our desired transmission range.

**2.4Ghz RF chip:** The 2.4Ghz RF module satisfies NFR8 (Range) as it has a transmission range of up to 1200m, although the NFR6 (video quality) does not seem achievable with a maximum data transmission rate of 2Mbps, analysis has been done on comparing video quality with the required bandwidth, the discussion can be seen in section 6.2.3.

**433MHz:** After a little research on the 433MHz communication module we discovered that we could achieve NFR5 (response time) and NFR8 (Range) except NFR6 (video quality) This is because its data rate is 9600bps, this is far off from the required bandwidth and almost impossible to suggest a tradeoff in this case. So, this solution cannot be adopted.

**Bluetooth:** This communication technology was found to satisfy only NFR5 (response time) and not NFR6 (video quality) and NFR8 (Range), this is because it has a data rate of about 2Mbps and a transmission range of 10m.

**4G/LTE Module:** The property of this technology satisfies almost all the NFRs, the technology has a maximum data rate of 150Mbps downlink and 50Mbps uplink thereby satisfying NFR5 (response time) and NFR6 (video quality). It also has a long transmission range, as this is determined by the availability of a cellular network of choice, thus satisfying NFR8 (Range). However, because of NFR14 which requires that the solution shouldn’t involve acquiring excessive licenses and certification, then this option cannot be adopted.

In summary, the table below shows a tabular summary of the wireless technologies and the requirements they fulfill.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | NFR5 (response time) | NFR6 (Video quality) | NFR8 (Range) | NFR14 (no certification and approval) |
| Bluetooth | Yes | No | No | Yes |
| 433Mhz | Yes | No | No | Yes |
| Wifi | Yes | Yes | No | Yes |
| 2.4Ghz | Yes | Yes | Yes | Yes |
| 4G/LTE | Yes | Yes | Yes | No |

From this analysis the best wireless communication technology that would help us achieve the most NFRs is the 2.4Ghz RF module.

### Signal Loss and Interference

Even with a strong, noise free signal, a radio link can get sudden dropouts, especially in cluttered or urban environments. This can be due to the reflected propagation path cancelling the direct propagation path. The cancelling occurs because of the phase shift associated with different propagation delays. This occurs at a specific point of the receiving space and can disappear just by moving the antenna less than one wavelength. The most intuitive way to avoid reflected signals is to have a directional focus at the line of sight. With directional antenna systems, the reflected signals will approach at an angle outside the main lobe of the antenna and will be attenuated. Directional antennas with a narrow beam and high directional gain will also increase the strength of the received signal from the drone and ensure good front-end channel filtering of the video receiver. The antenna can even be equipped with a tracker that automatically directs the antenna at the moving drone. A tracker would take GPS coordinates from the drone as input for the control system and the tracking algorithm [9].

### The Video capture system

This comprises of a camera module and a vehicle. The choice of wireless communication technology which was based on the requirements of the user would have appeared as a constraint for the options of camera module to select from.

The wireless communication module selected, at its best has a bandwidth of 2Mb/s == 400KB/s, this is not enough to meet up with the video quality requirement.

There are multiple factors that affect the overall quality of the video streaming such as frame rate etc. Resolution is one the most dominating and basic parameters because it directly reflects the details of the frames. We generally know the higher the resolution the better quality of video.

A picture containing timeline

Description automatically generated

*Figure 3: Resolution Spectrum*

The image above shows the resolution spectrum, it shows the different video resolutions and how they appear relative to each other. Resolution highly influences the user viewing experience, the larger the resolution the more enjoyable the experience would be, this justifies the NFR6 (Video quality) where the user requested a 1k resolution video. Below we would expatiate on each resolution and examine if the 2k resolution meets up with the non-functional requirements required for the links and communication system.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Resolution | Bitrate | size per min | size per sec |
| Ultra HD (UHD) | 2160p | 20 Mbps | 84MB | 1.4MB |
| Full HD (FHD) | 1080p | 5 Mbps | 20MB | 300KB |
| High Definition (HD) | 720p | 1 Mbps | 5MB | 80KB |
| Standard Definition (SD) | 480p | 0.5 Mbps | 2MB | 30KB |

*Table 2: Resolution and Bitrate*

The table above shows four video resolutions and their bitrate [10]. From this table, we can see the video resolution whose bitrate falls within the bandwidth of our preselected wireless communication technology, the 2.4 GHz RF module, we see that the 720p video resolution is the best option in video quality, this video quality option requires a 1 Mbps transmission rate, this is well within the capacity of the 2.4Ghz RF module because this module can transmit at 2Mbps. From this outcome, although we found an option that meets up with the existing requirement of long-distance wireless communication technology, we realize that this conflicts with the requirement for a high video resolution, hence we would like the customer and shareholders to re-evaluate these two requirements and select which of them is more important and should take more priority.

### The SWall

This includes the development of the software that would capture the streamed video data from the video capture system, since the choice of wireless communication technology is an RF module, we would purchase RF communication transceiver and Gateway that would receive and transmit this data to the SWall.

The SWall displays the recorded video. Towards the bottom of the screen, control buttons and gesture controls would be provided to pilot the drone and adjust the camera angle and view by the user. The application on the SWall would implement the NFR1 (Data encryption) while making sure there would be no third party access to satisfy NFR2 (Data privacy) Video streams will not be saved on the SWall locally, rather to another secured server or database.

## Verification

This part of the project requires the individual testing of all components suggested and outlined for each subsystem. Considering the purchase cost of each component, we opted to use a video review from the internet (YouTube) for each component. This video review will help us to test if the specification of each component meets our requirement, and also guide us to make bold decisions on which component to use.

### Link and communication

The following communication technologies were subjected to testing.

**Wi-Fi communication technology**: The Wio7c module from Electrodragon which has the esp8266 Wi-Fi chip on its module was tested in this experiment [10].

Using a TP-link WR-841W along with an external antenna on the Wio7c, the Wio7c module was able to cover a range of 479m. Without an external antenna on the Wio7c module i.e. with just its PCB antenna, it was only able to cover a distance of 316m with a 7% packet loss.

Using the UBIQITI M2 dish along with an external antenna, the Wio7c module covered a range of 4.28km with 6% packet loss. Without the external antenna i.e., with just its PCB antenna, it covered a range of 3.71km with no packet loss.

This test was conducted in a busy part of the city, where there were obstacles such as cars, structures, people, etc. It was beyond line-of-sight test [10].

The esp-01 Wi-Fi module was tested using the ESP-NOW protocol. In this test 2 esp-01 Wi-Fi modules were used, one as its transmitter, and the other as a receiver. At a range of 420m, 70% of data transmission was successful at direct line of sight. At a range of 250m, 100% of data transmission was successful at direct line of sight, also a round trip from sending the data to getting the acknowledgement back typically took 500us and, as the range stretches, it varies between 2000us to 20000us [11]. Only 250bytes payload can be carried by the ESP-NOW protocol.

**2.4Ghz RF:** Two (2) of the NRF24L0 module were used for the testing, one served as the transmitter and the other as a receiver. It was observed that, with a Yagi antenna attached to the receiver side and a dipole antenna attached to the transmitter side, the NRF24L0 was able to send over 500 packets of telemetry data each second at a distance of 1.8km. This test was conducted in an open area, where obstruction was very minimal [13].

**433MHz:** The FS100A and XY-MK-5V 433MHz were used for this test. The FS100A is the transmitter module while the XY-MK-5V served as the receiver. The 433MHz modules were attached with two antennas made of 16.5cm of copper wires. The First test scenario was in an open place with obstruction in the city of Berlin. The module was only able to transmit data, 1000 bit per seconds within a 4m distance. The second test scenario was in a field, with the same configuration and no obstruction. A distance of 315m was recorded, without any packet loss as long as the antennas were pointed vertically towards the sky [14].

**Bluetooth:** For the Bluetooth communication technology, two Bluetooth 5 nRF52840 development boards from Nordic Semiconductor were tested. The development board support both Bluetooth 4.2 and Bluetooth 5.0 technology. While testing the Bluetooth 4.2, it was observed that at a distance of 5m with a single wall in-between a throughput of 672Kbps (Kilobits per second) was attained, while for the same distance and obstacle the Bluetooth 5.0 was able give a throughput of 1215Kbps. At a distance of 11m with 2 walls in-between, Bluetooth 4.2 gave a throughput of 629Kbps while Bluetooth 5.0 gave a throughput of 900Kbps. At a distance of 18m with 4 walls in-between, Bluetooth 4.2 gave a throughput of 386Kbps while Bluetooth 5.0 gave a throughput of 470Kbps. At a distance of 11m, the Bluetooth 4.2 achieved a throughput of 533Kbps and the Bluetooth 5.0 a 584kbps throughput, all with 2 wall obstacles in-between them [12].

**4G/LTE:** The 4G/LTE module Huawei e3372h-510 on Verizon was used on this test to transmit telemetry data video coverage over a distance of approximately 17km. According to the test further could be achieved as long as there is cellular network in your desired destination [15]. In another test using a 4G/LTE module, a latency of 33ms on average was achieved [16].

After all these tests, we were able to ascertain the true specifications and limits of the above communication technologies, and also compare physically how much they satisfy our NRFs regarding to communication, we are very much still convinced that the 2.4GHz module is the right choice.

### The Video capture system

The Raspberry HQ pi camera and an actual raspberry pi (pi 4) board was tested. Under this test the author found out that the Broadcom video core IV GPU on the raspberry pi only supports the H.264 encoding, and the maximum resolution of video is 1080p at 30 frames per second. It was also observed that the pi HQ camera performs well at low light [17].

On this other test [18], the pi HQ camera was observed to be able to stream quality HD video at 48 frames per second without any problem.

The test on the pi HQ met our need, so we would be using it on this project.

### SWall

The SWall had two monitors attached to a row input HDMI converter which was fed to the laptop. The laptop had Ardupilot Mission planner software installed, and putty serial console installed. The putty was required to be able to make further changes on our raspberry pi that served as a video caption system of the drone, using SSH to login into the pi and access its command prompt.

## Conclusion

After verifying the specifications of the hardware components from result of experiments carried out by other authors, we will be focusing on the links and communication subsystem and carry out further experiments to justify the choice of module for this sub-system.

To satisfy our most recent interest, we have selected two components that would be used to verify all the requirements that are dependent on the link and communication module. The selected components are as given below;

1. NRF24L01 module

2. Raspberry Pi zero module

The NRF24L01 module is a module that operates at the 2.4GHz band. It will be interfaced with the Raspberry to form a complete standalone communication subsystem. Two of each of the listed components will be needed for this test, one NRF24L01 module and a Raspberry Pi zero module will serve as the link and communication subsystem for the ground station, while the other setup will serve as communication subsystem for the drone.

Software libraries and modules will be developed and used for this cause, and we will ensure they meet up with as much requirement as possible.

Two units of the NRF24L01 module will cost a total of $8.39 [20], and two units of the Raspberry Pi zero module will cost a total of $119.98 [21]. We can also make accommodation for additional single unit of the NRF24L01 module and Raspberry Pi zero module to give room for uncertainties like defective purchased hardware, or hardware failure or hardware damage in the cause of setting the system up.

### Link and Communication system architecture

Diagram

Description automatically generated

The image above shows the software and hardware component diagram for the approach of focusing on the Link and Communication sub-system requirements, i.e., NFR5 (response time), NFR6 (Video quality), NFR8 (Range) and NFR14 (no certification and approval). This would be designed and tested to see if it meets up with these requirements.

The “Raspberry pi Zero W [SWall]” would represent the SWall as we test the link and communication sub-system and its software interface. Video data would be read from the file system using the file system API and sent over the network from the Raspberry pi Zero. Events would be indicated on the GPIO interface

# Reference

1. “Video streaming over Wireless Networks,” IEEE Xplore. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/7099048/keywords#keywords. [Accessed: 4-Dec-2021]
2. A. Kaknjo, M. Rao, E. Omerdic, L. Robinson, D. Toal, and T. Newe, “Real-time video latency measurement between a robot and its remote control station: Causes and mitigation,” Wireless Communications and Mobile Computing, 02-Dec-2018. [Online]. Available: https://www.hindawi.com/journals/wcmc/2018/8638019/. [Accessed: 12-Jan-2022]
3. “Wireless Buying Guide,” *Wireless Buying Guide - SparkFun Electronics*. [Online]. Available: https://www.sparkfun.com/pages/wireless\_guide. [Accessed: 9-Jan-2022].
4. “Reliability, availability, and maintainability,” *The MITRE Corporation*, 26-Sep-2017. [Online]. Available: https://www.mitre.org/publications/systems-engineering-guide/acquisition-systems-engineering/integrated-logistics-support/reliability-availability-and-maintainability#:~:text=Definition%3A%20Reliability%2C%20Availability%2C%20and,LCC)%20of%20a%20developed%20system. [Accessed: 9-Jan-2022].
5. “Recommended upload encoding settings - youtube help,” *Google*. [Online]. Available: https://support.google.com/youtube/answer/1722171?hl=en#zippy=%2Cbitrate. [Accessed: 12-Jan-2022].
6. “How to accurately calculate video file size (plus: Bonus glossary),” *CircleHD*, 13-Nov-2019. [Online]. Available: https://www.circlehd.com/blog/how-to-calculate-video-file-size. [Accessed: 12-Jan-2022].
7. Ahmad-Loay, S., Daila, Y., & Mohamad , J. (2020). AES Encryption: Study & Evaluation. *researchgate.net*, 4-7.
8. B. Bergersen, "Drones and wireless video", *Datarespons.com*. [Online]. Available: https://datarespons.com/drones-wireless-video/. [Accessed: 13- Jan- 2022].
9. “Esp8266 WIFI range/distance tests (WI07C) - youtube.” [Online]. Available: https://www.youtube.com/watch?v=7BYdZ\_24yg0. [Accessed: 16-Feb-2022].
10. <https://www.youtube.com/watch?v=7BYdZ_24yg0>
11. https://www.youtube.com/watch?v=lOZpjhM\_94c
12. https://www.youtube.com/watch?v=756lbLk3Aqw
13. https://www.youtube.com/watch?v=zddC8rQasrg
14. https://www.youtube.com/watch?v=b0lVBJEH3fk
15. https://www.youtube.com/watch?v=KhKyPk6Gq9o
16. https://www.youtube.com/watch?v=iUctV-tqh\_M
17. https://www.youtube.com/watch?v=MVgr302PNwY
18. https://www.youtube.com/watch?v=DGAB34fJQFc
19. <https://www.youtube.com/watch?v=kB9YyG2V-nA>
20. “DIYmall ESP8266 ESP-01 ESP-01S WIFI serial,” *Amazon*. [Online]. Available: https://www.amazon.com/DIYmall-ESP8266-ESP-01S-Serial-Transceiver/dp/B00O34AGSU. [Accessed: 17-Feb-2022].
21. Vilros, “Vilros Raspberry Pi Zero W Basic Starter Kit,” *Amazon*. [Online]. Available: https://www.amazon.com/Vilros-Raspberry-Starter-Power-Premium/dp/B0748MPQT4. [Accessed: 17-Feb-2022].
22. https://www.guru99.com/non-functional-requirement-type-example.html