

Design Specification

For The

*Li-Fi Transmission System*



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# 1. Executive Summary

This document outlines the design specifications for the Li-Fi Transmission System developed by Group 13 for Team Projects I. All design decisions and requirements are outlined in Section 3 and 4 as taken from individual worksheets developed throughout the semester. These design decisions will be used to create a functioning data transmission system using Li-Fi VLC. That data would be hosted on a public website and a mobile application would have the ability to download and display all data transmitted. This design will be reviewed and accepted based on the validity of this document in conjunction with PDR and CDR presentations.

## Purpose of this document

This document is meant to describe how the Li-Fi system is to be constructed.

The hardware system architecture consists of an off-the-shelf, commercially available, programmable Li-Fi VLC system that consists of a pair of Raspberry Pi 4 computers, lasers, and solar panels. A 120V wall socket is available for powering the Raspberry Pi systems.

The software system architecture consists of 3 modules, the transmission system, the server, and an Android application. The transmission systems will communicate with each other via a Li-Fi VLC wireless system. One Pi, the server, and the Android application will communicate with each other via wi-fi.

## Design Scope

* The goal of this communication system is to transmit Death Star images to a Rebel Server from the Empire lab without being caught. The 10 images to be transmitted out of a possible 100 will be determined by a Death Star recognition application. These images on the server must then be accessed through a publicly hosted website by a group created mobile application by an authenticated user. This mobile application must be able to find potential Death Star weaknesses and display them in a scrollable table. The image transmission process from the lab can only be done through non-typical forms of communication and be end-to-end encrypted.
* Our proposed implementation of this communication system will use AES encrypted visible light communication (VLC), or Li-Fi, to transmit image data from the Empire Lab. This data will be received by a Li-Fi transceiver wired directly to the Rebel Server and uploaded to a website hosted using nginx. A C++ mobile application will be run on an Android mobile device to log into the website and download all 10 images. The weaknesses of these images will be displayed in a scrollable table on the same mobile device.

## Intended Audience and Document Overview

This document was developed for the use of potential future repeatability. This document will also be used as the guideline for design acceptance by the project sponsor.

## Definitions, Acronyms, and Abbreviations

* VLC (Visible Light Communication): The use of visible light frequencies as a transmission medium.
* Li-Fi (Light-Fidelity): A wireless communication technology that uses visible light for data transmission between devices.
* Raspberry Pi: A small single-board microcontroller that allows programming for multiple uses.
* USB (Universal Serial Bus): Industry standard interface for electronic data transmission and power supply.
* AES-256 (Advanced Encryption Standard): A symmetric encryption algorithm that uses block sizes of 256 bits.
* Script: An executable miniature program that can execute multiple Linux commands automatically.
* Transmission Raspberry Pi: Raspberry Pi utilized to transmit the evaluated 10 images of the Death Star outside of the Empire Lab.
* Receiver Raspberry Pi: Raspberry Pi utilized to receive the evaluated 10 images of the Death Star and transmit the md5 of the images back to the Empire Lab.
* SSH (Secure Shell Protocol): Protocol for secure data transmission over an unsecured network.
* URL (Uniform Resource Locator): Address for a given resource on the web.
* Rebel Server: The computer program hosting a website where images will be displayed.
* Medium: a tool used to deliver or store data.
* Mobile Application: The application that would be implemented to decipher red circles in 10 death star images.
* VAC: Volts of Alternating Current
* IEEE (Institute of Electrical and Electronics Engineers): Professional association for fields relating to electrical engineering.
* PEP (Python Enhancement Proposal): Design document for Python that defines and documents new features and processes.
* ISO (International Organization For Standardization): Organization that develops and publishes international standards.
* IEC (International Electrotechnical Commission): The leading organization for the preparation and publication of international standards for all electrical, electronic, and related technologies.
* FIPS (Federal Information Processing Standards): Organization that develops computer standards for non-military U.S. government agencies.
* NIST (National Institute of Standards and Technology): Federal organization that regulates standard practices related to fields of physical science.
* SHS (Secure Hash Standard): Standard to specify hash algorithms used to generate a digest of messages.
* PUB (Publication): Formal documentation.
* ANSI (American National Standards Institute): Organization that regulates information usage and transmission.
* IETF (Internet Engineering Task Force): Organization that creates standards for internet protocols.
* RFC (Request for Comments): Publication in a series from the principal technical development and standards-setting requirements for the internet.

## Document Conventions

Citations are in IEEE format.

## References and Acknowledgments

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* [8] Nerd Corner. Upgrade Data Transfer via VLC and LiFi Pi to Pi Transfer. [Online]. Available:<https://nerd-corner.com/upgrade-data-transfer-via-vlc-and-lifi-pi-to-pi-transfer/>
* [9] Z. Salim Alwan, Z. Tareq, and M. Younis, “Data Transmission using Li-Fi Technique”, Researchgate.net, April 2020.
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* [11] B. Bharath, D. Yaswanth, T. Ravi, and G. Jegan, “Bidirectional Communication in Li-Fi Technology”, ARPN Journal of Engineering and Applied Sciences, vol 11, no 13.
* [12] “Difference between LiFi and WiFi”, Geeksforgeeks.org, July 11, 2022

# Problem Statement

Secret plans for a military installation need to be transferred to an outside server utilizing a Raspberry Pi. The plans are contained in 10 Portable Network Graphics images that are 1024x1024 pixels. The transfer must be quick, traceless, and secure. Hash values utilizing the md5 sum algorithm must be transmitted back to be compared to the original hash values of the required data to be transferred thus requiring a bidirectional system. The data must be transferred wirelessly and in under 600 seconds or 10 minutes, including the md5 sum transfer and comparisons.

**Existing Solutions**

1. Utilizing radio waves such as with a 433Mhz Radio Transmitter, which is Bluetooth, cellular data, and Wi-Fi
2. The throughput of these methods ranges from approximately 150 Mbps for Wi-Fi and 3 Mbps for Bluetooth.
3. Wi-Fi has a limited frequency range that it can operate on in the GHz range, Wi-Fi also has the disadvantages of limited bandwidth, high power consumption and a relatively high price.

**Proposed Solution**

Li-Fi utilizes a Light Emitting Diode (LED) and a Light Dependent Resistor (LDR) to transfer data wirelessly between devices. Li-Fi systems operate in the optical spectrum as opposed to the radio wave spectrum. Li-Fi focuses on transmitting data through a LED-photodiode pair. Li-Fi transmits data at high speeds by turning the LED on or off using a binary format. The ‘1’ in the binary format turns on the LED and the ‘0’ turns off the LED, which results in pulses of light that are directed to the receiver [10]. For image transmissions, Li-Fi has the potential to use the Red, Green, Blue (RGB) Model and the Grayscale Mode. The RGB Model represents images in an integer scale ranging from 0 to 255. The Grayscale Mode is similar to the RGB Model where the colors are represented by the integer scale ranging from 0 to 255, but only consists of gray tones. Both transmission modes convert the image to binary based on the integer scale, transmit the binary data using ‘1’ and ‘0’, as stated above, then reverses the conversion process to obtain the original image on the receiver side [7]. Li-Fi also has the advantages of unlimited bandwidth, low power consumption, and low cost [12]. The throughput of Li-Fi is more than 1 Gbps for data transfer [9]. This allows for higher transmission rates and meets the time requirement of less than 10 minutes. Another advantage of Li-Fi is the reduced complexity [10]. By utilizing C Programming with the Li-Fi system, for both transmission and reception of the image, the algorithms are run simultaneously on both sides allowing the Baud rate to be the same [11]. While there is noise which could result in loss of data, an amplification device can be added which removes the noise, resulting in lossless data transmission through windows [11]. Li-Fi has the potential of using a band of frequencies in the THz range [9].

# Context of Design Solution

## Design Objectives

**Objective 1**: The wireless transmission system must transmit 10 1024x1024 pixel images and their hashes. This process must be without loss of data and should take under 10 minutes.

The chosen group transmission system needs to be able to transmit data without loss relatively quickly. For this objective, utilization of a VLC (Visible Light Communication), Li-FI system, will be used due to its fast transfer speed and ability for lossless transmission.

**Objective 2**: Create a wireless transmission system that is end-to-end encrypted.

All data that is sent must be encrypted before transmission and decrypted after transmission. There is no specific standard for encryption for this objective. Therefore, AES\_256 will encrypt all images and hashes before and after transmission. The sent data will then be decrypted using the same method.

**Objective 3**: Create a Python application that can evaluate 10 correct images of the Death Star out of a possible 100 images.

The ten images of the Death Star must be found programmatically out of a possible 100 images using a Raspberry Pi in the imperial lab. The Raspberry Pi will use pre-made Python libraries to find ten correct images. Only these ten evaluated images will be transmitted.

**Objective 4**: Create a transmission system where the md5 hashes of the images before and after transmission are the same.

To guarantee lossless transmission, images will be hashed before and after transmission. This will be done using md5 (message-digest algorithm) both before and after transmission. If hashes are not the same, then lossless transmission cannot be guaranteed.

**Objective 5**: Create a mobile application that evaluates the weaknesses of the 10 Death Star images and uploads them to an online server.

Evaluating the weaknesses of the transmitted Death Star images will be done by a group-created mobile application. This application will use Python libraries to find weak patterns in said images. The weakness will then be organized into a spreadsheet and uploaded to a server hosted by the group.

## Design Assumptions

**Assumption 1**: Testing will take place in the basement of the Russ building

**Assumption 2**: The project’s Raspberry Pi will be provided

**Assumption 3**: A Linux or Windows PC will be provided to house the web server.

**Assumption 4**: A USB thumb drive containing 100 images will be supplied.

**Assumption 5**: The Linux/Windows PC server will have access to the internet via WSU\_EZ\_Connect.

**Assumption 6**: All necessary power supplies will be supplied.

## Design Requirements

| Req No. | Obj No. | Requirement |
| --- | --- | --- |
| 10 | 1 | A VLC system utilizing Li-Fi must be built and provided using parts specified in the customer's budget. |
| 10.1 | 1 | Data shall be transmitted and received using a VLC, Li-Fi system. |
| 10.2 | 1 | No data shall be lost during the transmission process. |
| 10.3 | 1 | The Li-Fi system shall be set up using two Raspberry Pi’s. |
| 10.4 | 1 | Both Raspberry Pi’s implemented must have transmission and reception capabilities. |
| 10.5 | 1 | Image transmission software application for the transceiver system must be programmed using C++, C, or Python. |
| 10.6 | 1 | Empire Raspberry Pi must be able to download files from a USB drive. |
| 10.7 | 1 | Transmitted images must keep the original format after transmission. |
| 10.8 | 1 | There shall be no obstructions between the transmitter and receiver during image transmission. |
| 10.9 | 1 | The transceiving system must be low-power |
| 10.10 | 1 | The Empire and Rebel transceiving systems will take 5V±5% from their respective Raspberry Pi. |
| 20 | 2 | Wireless transmission must be encrypted and decrypted using AES-256 symmetric encryption. |
| 20.1 | 2 | The transmitted data before encryption and after decryption must be exact binary matches. |
| 20.2 | 2 | A password shall be used as a key for encryption and decryption verification. |
| 20.3 | 2 | A password shall be shared with only group members for encryption and decryption verification. |
| 20.4 | 2 | The Rebel Raspberry Pi must be able to decrypt the encrypted messages from the Empire Raspberry Pi. |
| 30 | 3 | An image evaluation software application must be created using an image processing library. |
| 30.1 | 3 | The image evaluation software application must identify the 10 correct images out of 100 and prepare them for data transmission. |
| 30.2 | 3 | All 100 images for the image evaluation application must be uploaded to the Empire Raspberry Pi. |
| 30.3 | 3 | The image evaluation application developed to evaluate Death Star pictures must be run on the Empire Raspberry Pi |
| 40 | 4 | A Linux script must be created to convert data to md5 sums. |
| 40.1 | 4 | A Linux data verification script must be used to compare the md5 sums for accurate data transmission confirmation. |
| 40.2 | 4 | A comparison of the md5 sums must be performed on the Empire Raspberry Pi after the transmission is completed. |
| 40.3 | 4 | The md5 sum of the transmitted data must be sent back to the Empire Raspberry Pi by the Rebel Raspberry Pi. |
| 50 | 5 | A mobile weakness evaluation software application shall be created to find weaknesses in the downloaded Death Star images. |
| 50.1 | 5 | The mobile weakness evaluation software application shall display a scrollable table with the Death Star weaknesses. |
| 50.2 | 5 | The mobile weakness evaluation software application must analyze the Death Star images to find the weaknesses depicted as separate red circles for each image. |
| 50.3 | 5 | The mobile weakness evaluation software application must depict each separate red circle once in a scrollable table. |
| 50.4 | 5 | A website hosted on the Rebel Server must be created and online during the mobile download. |
| 50.5 | 5 | Rebel Server must be able to be publicly connected to and allow users to download images if authenticated. |
| 50.6 | 5 | Rebel server must send a Youtube URL for the first video to any user connected to the public website. |
| 50.7 | 5 | User must login with the correct SSH key pair to view the second video on the public website once connected |
| 50.8 | 5 | Rebel server must send a secondary YouTube URL once the user is logged in to the public website |

## Design Constraints

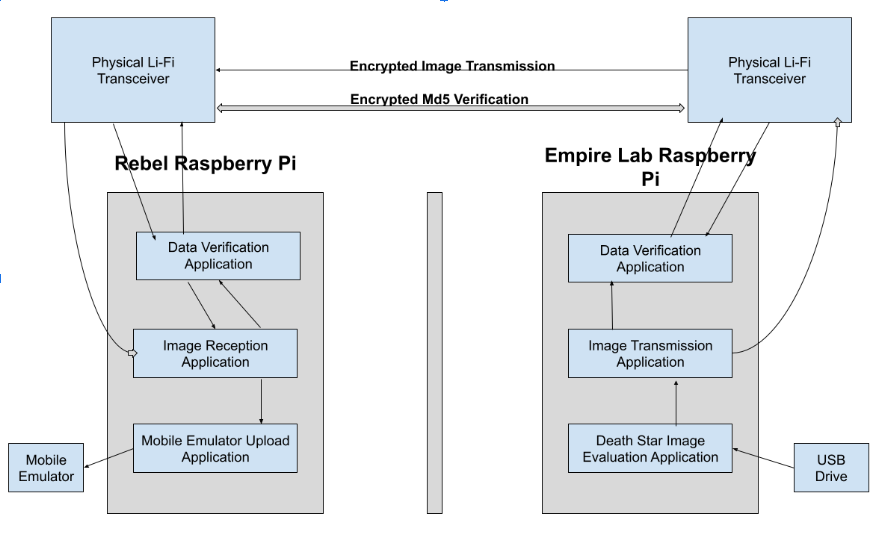
| Const No. | Constraint |
| --- | --- |
| 10 | Wifi, cellular data, and Bluetooth shall not be used as transmission mediums. |
| 20 | The total cost of materials must be 300 USD or less. |
| 30 | No electrical tethers shall be connected to the Empire Raspberry Pi |
| 40 | The complete solution must be demonstrated in the last week of the Fall 2024 semester. |
| 50 | The Rebel Server must be a minimum of 5 meters from the Raspberry Pi. |
| 60 | The system must be performed in the basement of the Russ Engineering Center. |
| 70 | The full system implementation must fit in the testing room of the Russ basement. |
| 80 | The development group shall include at least 4 members of different engineering disciplines. |
| 90 | The system must be able to perform at ambient temperature (60-80 degrees Fahrenheit). |
| 100 | No individual unit of the system shall weigh more than 10 pounds. |
| 110 | All electrical units of the system shall use standard 120VAC 60Hz as their input |

## Design Standards

| *Stand. No* | Standard |
| --- | --- |
| 10 | IEEE 802.11bb-23/0277rl: Standards on Light Communication, Volker Jungnickel, Lennert Bober, Tuncer Baykas, Nikola Serfimovski, San-Kyu Lim, 13-March-2023 |
| 20 | Python PEP: 8, Title: Style Guide for Python Code, Author: Guido van Rossum, 01-Aug-2013 |
| 30 | Federal Inf. Process. Stds. (NIST FIPS) - 197-upd1, May 9, 2023 |
| 40 | ISO/IEC 9899:2024, April 1, 2023 |
| 50 | FIPS PUB 180-4: Secure Hash Standard (SHS), August 4, 2015 |
| 60 | HTTPS |
| 70 | Information technology — Computer graphics and image processing — Portable Network Graphics (PNG): Functional specification. ISO/IEC 15948:2003 (E) |
| 80 | ANSI Z136 Laser Diode stds. |
| 90 | IETF RFC8017 RSA Cryptography Specifications |

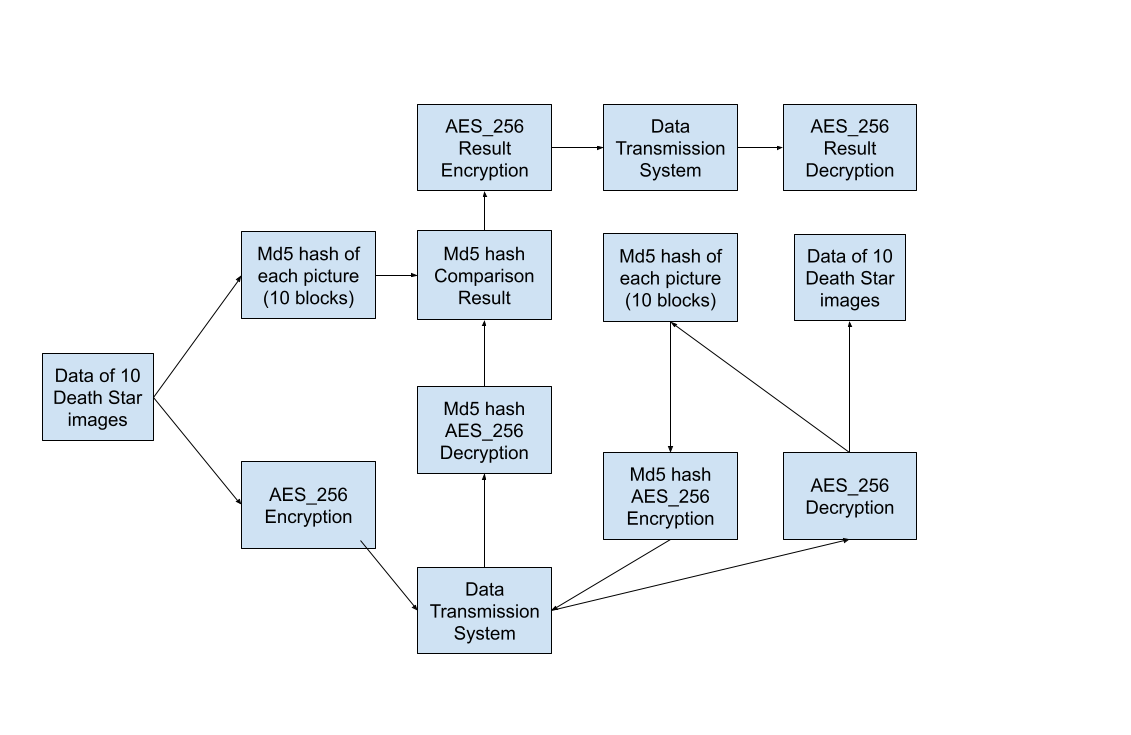
## Design Functionality

**Li-Fi Transmission System**

****

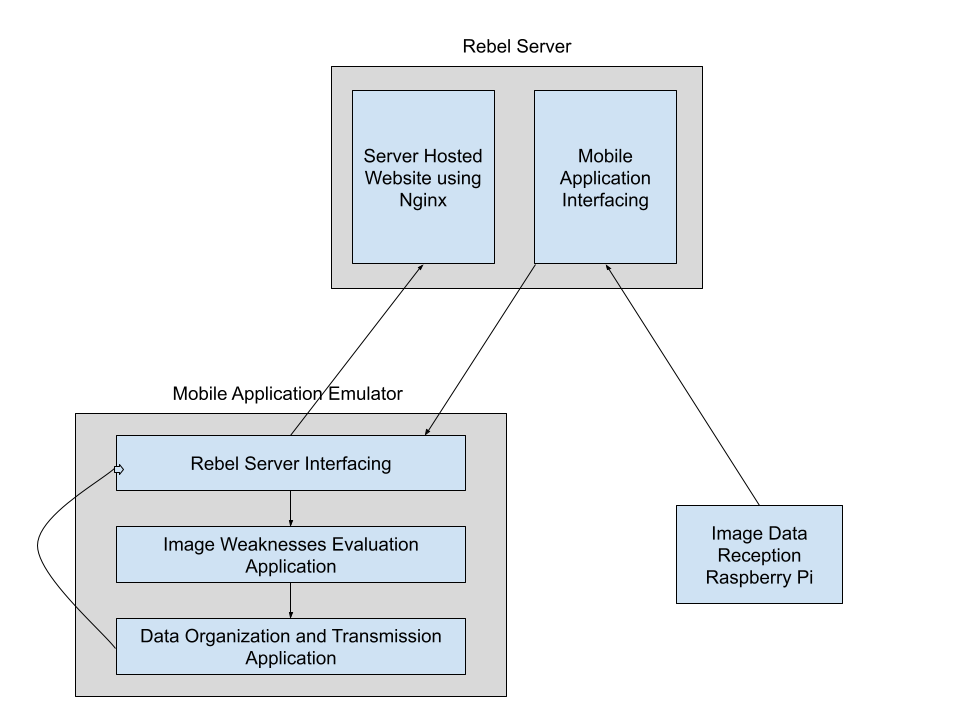
* Death Star images are uploaded to the Death Star image evaluation application of the Empire Lab Raspberry Pi.
* Once the 10 Death Star images are found, they are sent to the image transmission application.
* The image transmission application converts images into binary bits and sends them to the Li-Fi transceiver.
* The Li-Fi transceivers send and receive the image data and md5 sums in bidirectional communication.
* The Rebel Li-fi transceiver transfers the image data to the Image Reception Application.
* The Images are reconverted to PNG files and sent to the Data Verification Application.
* The Data Verification Application will hash each image using md5 sum and transfer each hash to the Rebel Li-Fi transceiver.
* The Imperial Li-Fi transceiver will transfer the md5 sum data to the Imperial Data Verification Application.
* The Imperial Data Verification Application will compare the transmitted md5 sum hash with the original image data hash and transmit it back if verified correctly.
* The Rebel Data Verification Application will pass the final verification of all image md5 sum data to the Image Reception Application.
* The Image Reception Application, upon receiving final verification, will transfer the images to the Mobile Application Emulator.

**Image Encryption and Data Verification System**



* The Md5 hash of each Death Star image is taken and stored for later comparison
* All data that is transmitted is first encrypted using AES\_256
* All encrypted image data is decrypted before any actions are performed on the images
* Hashes of the images must be retaken after decryption to verify lossless transmission
* Post-decryption hashes will be encrypted and transmitted back to the source
* Encrypted post-decryption hash data will be decrypted and compared to the original hashes of the images

**Mobile Application to Server System**



* The Rebel server receives the image data transmitted from the Imperial Lab.
* The Rebel server transmits the image data to the Mobile Application Emulator.
* Image data is evaluated for possible Death Star weaknesses and said weaknesses are recorded.
* Recorded weakness data is organized into a spreadsheet within the mobile application
* Data is prepared to be sent back to the Rebel Server.
* The Rebel Server takes the weak point data and hosts the data locally on a website.

## Design Impact

1. **Cultural**

One cultural benefit to implementing our system is the opportunity for further data transmission advancements. Li-Fi is a speed and efficiency improvement in comparison to most other wireless transmission methods and implementing such would lead to other improvements in the future. Moreover, real-time data can be transmitted to a website faster than with traditional methods using our system. One drawback of this technology would be that the physical space in which data is transmitted would have to be altered to be “in line of sight”.

2. **Economic**

A positive impact that Li-Fi has is the extremely low cost of components as compared to other wireless transmission methods. A negative economic impact of Li-Fi is that Wi-Fi companies will lose money as Li-Fi systems become more prevalent.

3. **Environmental**

One positive environmental benefit to the implementation of our system is that Li-Fi requires less power to operate than typical wireless transmission. This would make wireless transmission more energy efficient if widely used. Unfortunately, light transmission on a large scale would alter the habitats of local wildlife as animals would be drawn to transmission sources if they can be reached.

4. **Global**

One positive of our system globally is that the transmission medium is cheaper and therefore more accessible to areas with fewer resources for wireless transmission.

5. **Public health**

One positive of the Li-Fi system regarding public health is that there is no radiation emission compared to popular Wi-Fi systems. This can prevent several health concerns that come with radiation exposure. Additionally, medical professionals could benefit from faster-transmitting speeds when dealing with public health emergencies.

6. **Public safety**

One positive of the Li-Fi transmission system safety-wise is that there will be no interception of sensitive data as it is encrypted. Another positive of Li-Fi transmission is that it is a more secure transmission medium as intercepting light waves will always be obvious to a direct viewer. Additionally, public safety professionals could benefit from faster-transmitting speeds when dealing with safety emergencies.

7. **Public welfare**

A positive public welfare benefit of LiFi is that it is very cheap and affordable compared to Wifi which can benefit low-income citizens and families that need internet connection. One negative of the system would be the immediate cost of changing from WiFi to Li-Fi for the public.

8.  **Social**

One positive social effect would be the communication aspect that Li-Fi addresses. Li-Fi has high data transfer speeds and can be extremely effective regarding digital communication.

## User Characteristics

The user is intended to be anyone who desires to transmit data. The functionality of the system does not support more than one pet at a time. Ideally, the user will be someone who is regularly away from home for up to three days at a time. However, the system is not designed to be useful for any more than five meals. So, more than three days away and the device will no longer be able to feed the pet.

## Operating Environment

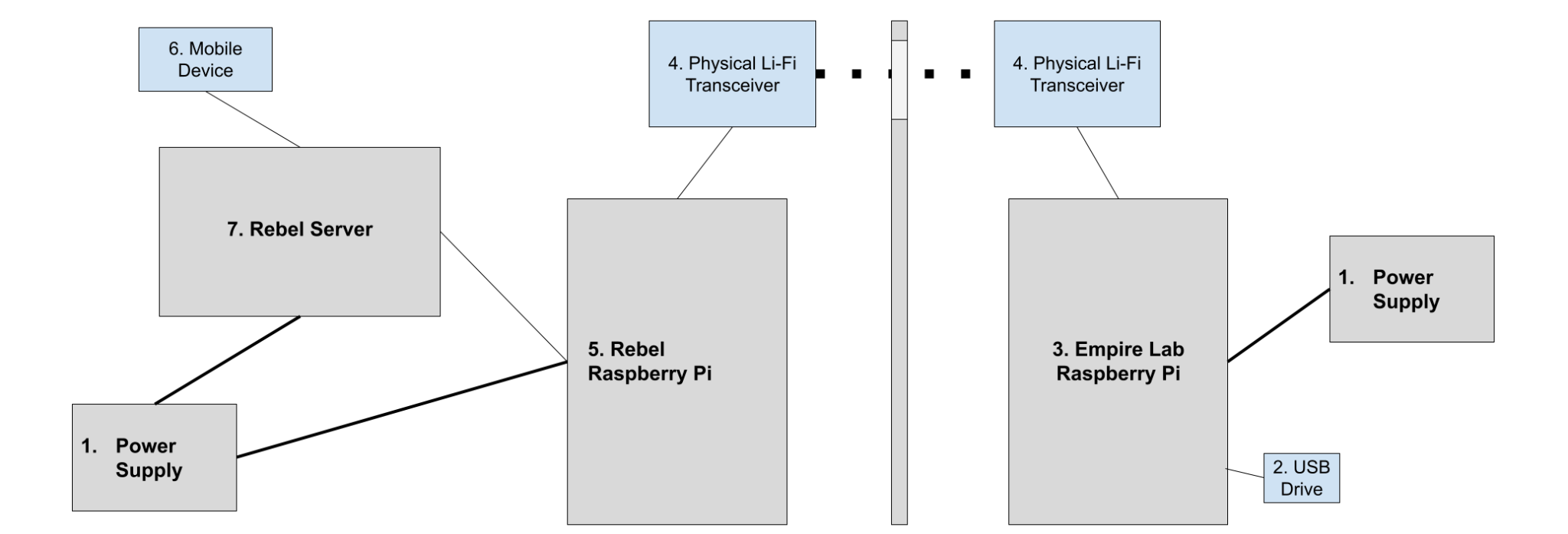
* Operating System:
  + It is required that the user have a phone with at least Android Version 9 as the operating system.
* Hardware:
  + The user must have access to a wifi network at all times.
* Environment
  + The system is intended to be used in the user’s home, and under the same conditions as similar home electrical appliances

## User Documentation

None

# Technical Approach

## Hardware



**Hardware Functional Block Definitions**

1. Power Supply- An electrical device that will supply power to Rebel Raspberry Pi and Rebel Server.
2. USB Drive- Supplied USB drive with the 100 images stored on it.
3. Empire Lab Raspberry Pi- Raspberry Pi within the Lab with the attached USB that contains the images.
4. Physical Li-Fi Transceiver- The wireless data transmission system. Transmits image data between the Lab and the Rebel Raspberry Pi.
5. Rebel Raspberry Pi- Raspberry Pi within the Lab that will receive the transferred images.
6. Mobile Device- An Android device that sorts and displays the Death Star images.
7. Rebel Server- Host server where a webpage to display the 10 Death Star images will be hosted

## Software

**Software Functional Block Definitions**

1. Death Star Image Evaluation application - Evaluates which of the 100 images are the 10 Death Star images.
2. Empire Lab Pi Image Transceiving application - Converts the images from PNG to binary in preparation for transmission and transmits and receives image data.
3. Empire Data Verification Application - An application used to encrypt, decrypt, hash each image, and verify the hashes of transmitted or received data.
4. Rebel Data Verification Application - An application used to encrypt, decrypt, hash each image, and verify the hashes of transmitted or received data.
5. Rebel Pi Image Transceiving application - Converts the images and hashes from PNG to binary in preparation for transmission and transmits and receives image data.
6. Raspberry Pi to Server Interfacing - Sends packaged image data to the Rebel Server using a wired connection.
7. Server Hosted Website using Nginx - Locally hosted website that will use Nginx to take image data, and allow for the user to download the uploaded images.
8. Mobile Download application - Application that will be used to package and download images to the mobile application.
9. Image Weakness Evaluation Application - An application that will sort through the 10 downloaded images to determine weaknesses in the Death Star.
10. Data Organization and Display Application - An application that will sort the image weaknesses into a scrollable table and then display them on the mobile device.
11. Authenticated Public Website - Website hosted by Rebel Server that allows for all users to view a Youtube video. Only authenticated users with the correct ssh keypair can download images and view secondary Youtube video.

# Appendix: Test and Evaluation Master Plan and Report

Test and Evaluation plan was created based off of the specifications of worksheet 4.3 and 4.4. Design is only ready for implementation when the Master Test Plan Report is completed and passed for all individual tests.

**Hardware Design Choices:**

1. **Rebel Raspberry Pi**

|  | **Design Options** | | | |
| --- | --- | --- | --- | --- |
| ***Criteria*** | ***Raspberry Pi 4, 2GB*** | ***Raspberry Pi 4, 4GB*** | ***Raspberry Pi 4, 4GB, 64Gb Memory*** | ***Raspberry Pi 4, 4GB, 256GB Memory*** |
| ***Req. 10.4*** | Could have transmission and reception capabilities. | Could have transmission and reception capabilities. | Could have transmission and reception capabilities. | Could have transmission and reception capabilities. |
| ***Const. 20***  ***(Budget)*** | Low cost  (54$ for Pi and Server Connection) | Low cost  ($64 for Pi and Server Connection) | High cost  ($71.3 for Pi and Server Connection) | High cost with no return.  ($101.51 for Pi and Server Connection) |
| ***Req. 10.5*** | Not enough memory to contain all the programs | Not enough memory to contain all the programs | Enough storage to contain all programs | Enough storage to contain all programs |
| ***Req. 20.4*** | No Operating System | No Operating System | Can use OpenSSL for AES | Can use OpenSSL for AES |
| ***Req. 10.1***  ***(GPIO pins)*** | Can interface with transceiver system | Can interface with transceiver system | Can interface with transceiver system | Can interface with transceiver system |
| ***Std. 70*** | Cannot store .png files in the correct format | Cannot store .png files in the correct format | .png files can be stored in the correct format | .png files can be stored in the correct format |

The Raspberry Pi 4 with 4GB of RAM and 64GB of removable memory will be used for this hardware block. This device would be able to fill all requirements for the least necessary cost of the devices decided upon. The software planned on being used requires the device to have some form of storage and therefore the Raspberry Pis without memory cannot be used. Any size of memory larger than 64GB would be more expensive than what is needed and therefore the Raspberry Pi with 256GB of memory is not used.

1. **Li-Fi Transceiver System**
   1. **Transmission Capabilities**

|  | **Design Options** | | | |
| --- | --- | --- | --- | --- |
| ***Criteria*** | ***400nm laser*** | ***535nm Laser*** | ***650nm laser*** | ***470nm LED light*** |
| ***Req. 10.1*** | Can implement Li-Fi transmission | Can implement Li-Fi transmission | Can implement Li-Fi transmission | Can implement Li-Fi transmission |
| ***Req. 10.9*** | Part is low power, high cost | Part is low power, high cost | Part is low power and cost | Part is low power and cost |
| ***Req. 10.2*** | Lossless transmission | Lossless transmission | Lossless transmission | Lossless transmission |
| ***Req 10.4*** | Can interface with Raspberry Pi | Can interface with Raspberry Pi | Can interface with Raspberry Pi | Can interface with Raspberry Pi |
| ***Reg. 10.10*** | Input power of < 5V | Input power of < 5V | Input power of 5V | Input power of < 5V |
| ***Std. 10*** | Follows typical Li-Fi standard | Follows typical Li-Fi standard | Follows typical Li-Fi standard | Follows typical Li-Fi standard |
| ***Const. 50*** | Can transmit beyond 5 meters | Can transmit beyond 5 meters | Can transmit beyond 5 meters | Can not transmit beyond 5 meters |
| ***Const. 20 (Budget)*** | Higher Cost  ($42.97) | Higher Cost  ($42.97) | Low Cost  ($36.92) | Low Cost  ($36.92 20-Pack) |

* 1. **Reception Capabilities**

|  | **Design Options** | | |
| --- | --- | --- | --- |
| ***Criteria*** | ***5V, 1A, Solar Cell*** | ***6V, .8A, Solar Cell*** | ***Photodiode Sensor*** |
| ***Req. 10.1*** | Can implement Li-Fi reception | Can implement Li-Fi reception | Can implement Li-Fi reception |
| ***Req. 10.2*** | Lossless Reception | Lossless Reception | Lossless Reception |
| ***Req 10.4*** | Can interface with Raspberry Pi | Can interface with Raspberry Pi | Can interface with Raspberry Pi |
| ***Req. 10.8*** | No obstructions present | No obstructions present | No obstructions present, needs excessive precision |
| ***Req 10.9*** | low cost, low power | Low cost, low power | Low cost, low power |
| ***Req 10.10*** | Takes 5V input | Takes 5V input after manipulation | Takes > 5V input |
| ***Const. 20***  ***(Budget)*** | Low Cost  ($8.95 for laser and implementation) | Higher Cost  ($20.95 for laser and implementation) | Higher Cost  ($24.97 for laser and implementation) |
| ***Std. 10*** | Follows typical Li-Fi standard | Follows typical Li-Fi standard | Follows typical Li-Fi standard |

The 650nm laser in conjunction with the 5V@1A solar cell will be used for our Li-Fi transceiver system. The 650nm laser takes in the correct input power as opposed to the other possible transmission modules as well as being low-cost. The 650nm laser can also transmit the required 5 meters from the Empire Lab. The 5V@1A solar cell takes in the required 5V input while being low power and low cost. Moreover, The 5V solar cell will be able to take in the required input without circuit manipulation in comparison to the other reception devices.

1. **Mobile Device**

|  | **Design Options** | | | |
| --- | --- | --- | --- | --- |
| ***Criteria*** | ***iPhone 12 Pro*** | ***Samsung Galaxy S23+*** | ***Samsung Galaxy S23+ Emulator*** | ***iPhone 12 Pro Emulator*** |
| ***Const. 20***  ***(Budget)*** | Personally Owned | Personally Owned | Little to no cost to implement | Cost of operating system |
| ***Req. 50.1*** | Able to display scrollable table (Limited) | Able to display scrollable table | Able to display scrollable table | Able to display scrollable table (Limited) |
| ***Req. 50.2*** | Able to run user-created software (Limited) | Able to run user-created software | Able to run user-created software | Able to run user-created software (Limited) |
| ***Req. 50.4*** | Able to connect to the server over Wi-Fi | Able to connect to the server over Wi-Fi | Able to connect to the server over Wi-Fi | Able to connect to the server over Wi-Fi |

A personally owned Samsung Galaxy S23+ will be used for the mobile device. Due to low familiarity with Swift coding language, iPhones would be harder to implement. An Android mobile device would be easier to implement due to already being personally owned, and a higher familiarity with the C++ coding language. We also have a physical device available for use so we will choose that over an emulator.

1. **Rebel Server**

|  | **Design Options** | |
| --- | --- | --- |
| ***Criteria*** | ***Windows*** | ***Linux*** |
| ***Std. 60*** | OS can follow HTTPS protocols | OS can follow HTTPS protocols |
| ***Req. 50*** | Hosted Server can allow downloads | Hosted Server can allow downloads |
| ***Req 50.4*** | Can host a server | Can host a server |
| ***Const. 50*** | The server can be placed within 5 meters of Empire Lab | The server can be placed within 5 meters of Empire Lab |
| ***Req 50.5*** | The server can be publicly connected using Nginx (Limited) | The server can be publiclyconnected using Nginx |

A Linux OS will be used for the Rebel Server. A Linux system is easier to implement due to more familiarity with coding and running websites and servers. Linux servers are much less of a hassle when setting up and operating. Nginx software will be used to host the server which the group has experience running in Linux.

**Software Design Choices:**

|  | **Design Options** | | |
| --- | --- | --- | --- |
| ***Criteria*** | ***Python*** | ***C++*** | ***Java*** |
| ***Std. 70*** | pillow library can process .png images | pillow library can process .png images | pillow library can process .png images |
| ***Std. 20*** | Follows Python coding standards | Does not follow Python coding standards | Does not follow Python coding standards |
| ***Req. 30*** | pillow library can process .png images | OpenCV library can process .png images | OpenCV library can process .png images |
| ***Req. 30.1*** | The library can theoretically identify Death Star images | The library can theoretically identify Death Star images | The library can theoretically identify Death Star images |
| ***Req 30.3*** | Can be run on Raspberry Pi | Can be run on Raspberry Pi | Can be run on Raspberry Pi |

Python will be used in conjunction with the pillow image processing library to develop the Image Evaluation Application. Proof of work has been shown to verify that the pillow libraries will be able to find Death Star pictures in groups of similar objects. OpenCV and therefore Java and C++ would be much harder to implement than Python because Pillow is created for Python specifically whereas OpenCV is not.

1. **Empire Lab Pi Image Transceiving Application**

|  | Design Options | | |
| --- | --- | --- | --- |
| ***Criteria*** | ***Python*** | ***C++*** | ***C*** |
| ***Const. 10*** | Interfaces with Li-Fi system using WiringPi Library (limited) | Interfaces with Li-Fi system using WiringPi Library | Interfaces with Li-Fi system using WiringPi Library |
| ***Req. 10.5*** | Applicable software language | Applicable software language | Applicable software language |
| ***Req. 10.4*** | Will use both received and transmitted data | Will use both received and transmitted data | Will use both received and transmitted data |
| ***Req. 10.7*** | Can transmit file formatting data | Can transmit file formatting data | Can transmit file formatting data |
| ***Std. 40*** | Does not follow C++ coding standards | Follows C++ coding standards | Follows C coding standards |

C coding language will be used to implement the Image Transceiving Application. This is because C interacts with the GPIO pins of the Raspberry Pi with the least overhead work using an external library compared to other languages. Moreover, code found by the group during research which will be used as a baseline, used C for their work.

1. **Empire Data Verification Application**

|  | Design Options | |
| --- | --- | --- |
| **Criteria** | **Bash** | **Korn Shell** |
| **Req. 20** | Can implement Openssl AES-256 encryption/decryption | Can implement Openssl AES-256 encryption/decryption (limited) |
| **Req. 20.1** | Can compare binary file values | Can compare binary file values |
| **Req. 20.2** | Can implement Openssl AES-256 encryption/decryption | Can implement Openssl AES-256 encryption/decryption (limited) |
| **Req. 40** | Can implement scripting and md5 | Can implement scripting and md5 |
| **Req. 40.1** | Can implement scripting and md5 | Can implement scripting and md5 |
| **Req. 40.2** | Bash shell is preloaded on Empire Raspberry Pi OS | It would have to be installed separately on Empire Raspberry Pi. |
| **Std. 50** | AES-256 follows common encryption standard | AES-256 follows common encryption standard |

Bash scripting will be used to implement the Empire Data Verification Application. This is because bash is more comfortable for the design team to implement. Additionally, bash is native to the common Raspberry Pi operating system where Korn shell would have to be installed separately.

1. **Rebel Data Verification Application**

|  | Design Options | |
| --- | --- | --- |
| **Criteria** | **Bash** | **Korn Shell** |
| **Req. 20** | Can implement Openssl AES-256 encryption/decryption | Can implement Openssl AES-256 encryption/decryption (limited) |
| **Req. 20.1** | Can compare binary file values | Can compare binary file values |
| **Req. 20.2** | Can implement Openssl AES-256 encryption/decryption | Can implement Openssl AES-256 encryption/decryption (limited) |
| **Req. 40** | Can implement scripting and md5 | Can implement scripting and md5 |
| **Req. 40.1** | Can implement scripting and md5 | Can implement scripting and md5 |
| **Req. 40.2** | Bash shell is preloaded on Empire Raspberry Pi OS | It would have to be installed separately on Empire Raspberry Pi. |
| **Std. 50** | AES-256 follows common encryption standard | AES-256 follows common encryption standard |

Bash scripting will be used to implement the Rebel Data Verification Application. This is because bash is more comfortable for the design team to implement. Additionally, bash is native to the common Raspberry Pi operating system where Korn shell would have to be installed separately.

1. **Rebel Pi Image Transceiving Application**

|  | Design Options | | |
| --- | --- | --- | --- |
| ***Criteria*** | ***Python*** | ***C++*** | ***C*** |
| ***Const. 10*** | Interfaces with Li-Fi system using WiringPi Library (limited) | Interfaces with Li-Fi system using WiringPi Library | Interfaces with Li-Fi system using WiringPi Library |
| ***Req. 10.5*** | Applicable software language | Applicable software language | Applicable software language |
| ***Req. 10.4*** | Will use both received and transmitted data | Will use both received and transmitted data | Will use both received and transmitted data |
| ***Req. 10.7*** | Can transmit file formatting data | Can transmit file formatting data | Can transmit file formatting data |
| ***Std. 40*** | Does not follow C++ coding standards | Follows C++ coding standards | Follows C coding standards |

C coding language will be used to implement the Image Transceiving Application. This is because C interacts with the GPIO pins of the Raspberry Pi with the least overhead work using an external library compared to other languages. Moreover, code found by the group during research which will be used as a baseline, used C for their work.

1. **Raspberry Pi to Server Interfacing**

|  | Design Options | |
| --- | --- | --- |
| **Criteria** | **Bash** | **Korn Shell** |
| **Req. 50** | Can move images to the server for hosting | Can move images to the server for hosting (limited) |
| **Req. 50.5** | Can move images to the server for hosting | Can move images to the server for hosting (limited) |
| **Std. 70** | Can send data as formatted .png’s | Can send data as formatted .png’s |

Bash will be used to move image data to the server. This is because Bash was used previously and there is no additional benefit of using a different shell script.

1. **Server Hosted Website**

|  | Design Options | | | | |
| --- | --- | --- | --- | --- | --- |
| ***Criteria*** | ***Nginx*** | ***Bash*** | ***Apache*** | ***AWS*** | ***Oracle*** |
| **Req. 50.4** | Can be created and be online during mobile download process | Can be created and be online during mobile download process | Can be created and be online during mobile download process | Can be created and be online during mobile download process | Can be created and be online during mobile download process |
| **Std. 60** | Can support HTTPS connections | Can support HTTPS connections (complicated) | Can support HTTPS connections | Can support HTTPS connections (high cost) | Can support HTTPS connections (high cost) |
| **Req. 50.5** | Can be publicly connected to and allow users to download images | Can be publicly connected to and allow users to download images | Can be publicly connected to and allow users to download images | Can be publicly connected to and allow users to download images | Can be publicly connected to and allow users to download images |

Though all web servers listed do not have any specific disadvantages, Nginx will be used as the web server where the website will be hosted as the team is more familiar with Nginx than other aforementioned web servers.

1. **Mobile Download Application**

|  | Design Options | | | |
| --- | --- | --- | --- | --- |
| ***Criteria*** | ***Swift*** | ***C++*** | ***Rust*** | ***Python*** |
| ***Req. 50.4*** | Can connect to server using HTTPS | Can connect to server using HTTPS | Can connect to server using HTTPS | Can connect to server using HTTPS |
| ***Req. 50.5*** | Can pull data from the server using HTTPS | Can pull data from the server using HTTPS | Can pull data from the server using HTTPS (Limited) | Can pull data from the server using HTTPS |
| ***Std. 60*** | Can send data following HTTPS | Can send data following HTTPS | Can send data following HTTPS | Can send data following HTTPS |
| ***Std. 40*** | Does not follow C++ coding standards | Follows C++ coding standards | Does not follow C++ coding standards | Does not follow C++ coding standards |

C++ will be used for the Mobile Download Application due to its flexibility and the amount of tools that will be needed for downloads and HTTPS compatibility. We are also using an Android device and they use C++ for their app development so most resources would also use C++.

1. **Image Weakness Evaluation Application**

|  | Design Options | | | |
| --- | --- | --- | --- | --- |
| ***Criteria*** | ***Swift*** | ***C++*** | ***Rust*** | ***Python*** |
| ***Req. 50*** | Theoretically possible but not proven | Possible using external libraries | Theoretically possible but not proven | Possible using external libraries |
| ***Req. 50.2*** | Theoretically possible but not proven | Possible using external libraries | Theoretically possible but not proven | Possible using external libraries |
| ***Req. 50.5*** | Allows for image download from URL | Allows for image download from URL | Allows for image download from URL (Limited) | Allows for image download from URL |
| ***Std. 60*** | Can send data following HTTPS | Can send data following HTTPS | Can send data following HTTPS | Can send data following HTTPS |
| ***Std. 40*** | Does not follow C++ coding standards | Follows C++ coding standards | Does not follow C++ coding standards | Does not follow C++ coding standards |
| ***Std. 70*** | Can send and store data in .png format | Can send and store data in .png format | Can send and store data in .png format | Can send and store data in .png format |

C++ will be used on the mobile device to implement the Weakness Evaluation Application. This is because C++ has familiar image evaluation libraries that can be used to find the red circles containing possible weaknesses. Swift and Rust also have these libraries but proof of work with their usage cannot be found. Python achieves the requirements but is not being used because the group is more comfortable with C++.

1. **Data Organization and Display Application**

|  | Design Options | | | |
| --- | --- | --- | --- | --- |
| ***Criteria*** | ***Swift*** | ***C++*** | ***Rust*** | ***Python*** |
| ***Req. 50.3*** | Possible using external libraries | Possible using external libraries | Theoretically possible but not proven | Possible using external libraries |
| ***Std. 40*** | Does not follow C++ coding standards | Follows C++ coding standards | Does not follow C++ coding standards | Does not follow C++ coding standards |
| ***Std. 70*** | Can send and store data in .png format | Can send and store data in .png format | Can send and store data in .png format | Can send and store data in .png format |

C++ will be used to program the Data Organization and Display Application on the mobile device. This is because the group is more comfortable working with C++ than Swift and Python. Rust theoretically could work however no proof of work was found by the group.

***Master Test Plan:***

***Requirement Test Plan***

| ***Req No.*** | ***Test Method*** | ***Evaluation Method*** | ***Threshold*** | ***Objective*** |
| --- | --- | --- | --- | --- |
| ***10*** | *Add up the cost of all components and compare them to the budget.* | *Verify the cost of all components complies with the listed budget.* | *The cost of all components must be less than $300.* | *The cost should be as low as possible while meeting all other requirements.* |
| ***10.1*** | *Check the data transmission system.* | *Verify that the data transmission system utilizes a VLC system, specifically Li-Fi.* | *See visual output and have data be equal hex value post-transmission.* | *The system utilizes visible light to transmit and receive data.* |
| ***10.2*** | *Verify the md5sum data of the transmitted images matches the md5sum of the original images.* | *Code analysis in conjunction with a built-in test to verify that the hashes match.* | *All hashes of transmitted data and untransmitted data match.* | *Each hash should match with per image.* |
| ***10.3*** | *Check if there are 2 Raspberry Pi computers.* | *Visual confirmation that there are 2 Raspberry Pi devices.* | *2 Raspberry Pi computers give I/O responses.* | *Raspberry Pis can run test code to prove operational.* |
| ***10.4*** | *Check if both Raspberry Pis can transmit and receive data.* | *Visual confirmation that both Raspberry Pis have both laser and solar cells to send and receive data.* | *Both Raspberry Pi systems have a laser transmitter and solar cell receiver.* | *Each Raspberry Pi should have the ability to send and receive data.* |
| ***10.5*** | *Check coding language to ensure that either C, C++, or Python is used.* | *Visual confirmation that the transceiver system is coded in either C, C++, or Python.* | *No obscure language is used to code the transceiver application.* | *Code can compile with no errors.* |
| ***10.6*** | *Check if Empire Pi can download files from a USB drive.* | *Download sample files from a USB drive onto the Empire Pi.* | *files download successfully from USB without corruption.* | *Verify all files from the USB exist on the Raspberry Pi.* |
| ***10.7*** | *Check if each image format is the same after transmission.* | *Visual confirmation that each image format is the same for each image* | *Image formats are the same before and after transmission* | *Each image should show image format when opened in a text editor.* |
| ***10.8*** | *Check if there are obstructions between the transmitter and receiver during transmission.* | *Visual confirmation that there are no obstructions.* | *Transmitter and receiver can communicate efficiently with each other.* | *Transmitter and receiver should be able to communicate with each other with little to no obstruction.* |
| ***10.9*** | *Check that the transceiving system is powered by 10 volts or less.* | *Verify that the transceiving system can be powered by 10 volts or less using voltage readings.* | *Transceiving system is powered by 10 volts or less.* | *The power drawn should be as low as possible while meeting all other requirements.* |
| ***10.10*** | *Check if both Empire and Rebel transceiving systems take in 5V from their respective Raspberry Pi.* | *Verify that both Empire and Rebel transceiving systems can be powered by 5V from their respective Raspberry Pi using voltage readings.* | *Empire and Rebel transceiving systems take in* 5V±5% *from respective Raspberry Pis.* | *Empire and Rebel transceiving systems can take in 5V from their respective Raspberry Pis.* |
| ***20*** | *Look at the encrypted file to visually check the ciphertext in hex.* | *Visual confirmation of ciphertext and plaintext to ensure data is encrypted and decrypted.* | *Text should be encrypted and decrypted utilizing AES-256.* | *Transmission should be encrypted and decrypted using AES-256.* |
| ***20.1*** | *Check if data binaries are the same before and after transmission.* | *Verify data binaries are the same before and after transmission.* | *Data binaries are the same before and after transmission.* | *Data binaries should be the same before and after transmission.* |
| ***20.2*** | *Check if password is required for encryption and decryption.* | *Visual confirmation of password request for encryption and decryption functions* | *Password required to implement encryption and decryption of data.* | *Entered password encrypts or decrypts transmitted data.* |
| ***20.3*** | *Check that all group members know the password.* | *Verify all group members know the password key.* | *All group members know the password key.* | *Each group member enters the correct password to encrypt and decrypt the data.* |
| ***20.4*** | *Check that Rebel Raspberry Pi can decrypt encrypted messages from the Empire Raspberry Pi.* | *Verify that Rebel Raspberry Pi can decrypt encrypted messages from the Empire Raspberry Pi.* | *Rebel Raspberry Pi must decrypt encrypted messages from the Empire Raspberry Pi.* | *Rebel Raspberry Pi must decrypt encrypted messages from the Empire Raspberry Pi.* |
| ***30*** | *Verify an image processing application is on the device.* | *Verify an uploaded picture can be processed via the application.* | *Image evaluation must occur using PNG images.* | *The image evaluation application is able to process images for specific data points.* |
| ***30.1*** | *Verify the image evaluation application can identify 10 Death Star images out of 100.* | *Verify image evaluation software can correctly identify 10 images out of 100.* | *The image evaluation process must be able to identify the correct 10 images containing red circles out of 100 possible images.* | *The image evaluation program must be able to scan, process, and identify 10 images out of 100 that contain red circles.* |
| ***30.2*** | *Verify that the 100 images from the USB are successfully loaded onto the Empire Raspberry Pi.* | *Verify that all 100 images from the USB are copied onto the Empire Raspberry Pi.* | *All 100 images must be accessed and uploaded onto the Empire Raspberry Pi for image evaluation.* | *Confirm that all 100 images are accessed, copied, and prepared for image evaluation.* |
| ***30.3*** | *Visually confirm that the Empire Raspberry Pi has the image evaluation program installed and can be executed.* | *Verify that the image evaluation program is installed and can only be executed on the Empire Raspberry Pi.* | *Verify the image evaluation program is installed and can only be executed on the Empire Raspberry Pi.* | *The image evaluation program is used on the Empire Raspberry Pi to process the 100 images for the Death Star plans.* |
| ***40*** | *Check that it is a Linux script that converts data to md5 sums.* | *Verify that the Linux script converts data to md5 sums.* | *Data must be converted to md5 sums.* | *Create a Linux script that must be able to convert data to md5 sums.* |
| ***40.1*** | *Check that md5 sums are compared using a Linux data verification script.* | *Verify that there is accurate data transmission confirmation of md5 sums that were compared using a Linux data verification script.* | *Confirmation of accurately transmitted data must be done by comparing md5 sums using a Linux data verification script.* | *Create a Linux data verification script that compares md5 sums for accurate data transmission confirmation.* |
| ***40.2*** | *Check that the comparison of md5 sums is done on the Empire Raspberry Pi after one image is transmitted* | *Observe comparison of md5 sums is performed on the Empire Raspberry Pi using an instance of one image in a debug instance* | *Comparison of md5 sums must be performed on the Empire Raspberry Pi before another image is transmitted.* | *Comparison of md5 sums must be done after transmission is completed for all images on the Empire Raspberry Pi.* |
| ***40.3*** | *Check that the md5 sum of transmitted image is sent to the Empire Raspberry Pi by the Rebel Raspberry Pi for one image* | *Observe that the md5 sum of transmitted data is sent to the Empire Raspberry Pi by the Rebel Raspberry Pi using one image in a debug instance* | *The md5 sum of transmitted data is sent to the Empire Raspberry Pi by the Rebel Server and the system is ready to send the next image.* | *The md5 sum of transmitted data must be sent to the Empire Raspberry Pi by the Rebel Server.* |
| ***50*** | *Check the mobile device has a program to evaluate the weaknesses of the Death Star plans.* | *Verify the mobile device has an application to evaluate the weaknesses of the Death Star plans.* | *The mobile application must be able to evaluate the weaknesses of the Death Star plans.* | *The mobile application must be able to evaluate each image for the weaknesses depicted within the red circles.* |
| ***50.1*** | *Verify that the table created by the weakness evaluation application is scrollable.* | *Ensure that the evaluation program creates a scrollable table to display the evaluated weaknesses.* | *Confirm the evaluation program creates a scrollable table to display the evaluated weaknesses.* | *The mobile weakness evaluation application needs to create a scrollable table and display the weaknesses.* |
| ***50.2*** | *Check if mobile weakness evaluation software applications can recognize the weaknesses depicted as separate red circles for each image*. | *Verify that the mobile weakness evaluation software application can recognize the weaknesses depicted as separate red circles for each image*. | *The application finds all possible weaknesses in the 10 images.* | *Make sure that all the weaknesses are found in the 10 images by the mobile weakness evaluation software application.* |
| ***50.3*** | *Verify that each evaluated weakness is depicted once in the table.* | *Ensure that each weakness the red circles depicts is shown only once on the scrollable table.* | *Verify that each depicted weakness is shown only once on the scrollable table.* | *The scrollable table shows each depicted weakness only once.* |
| ***50.4*** | *Check the website has been created and is online via the Rebel Server.* | *Verify the website is online and able to be connected during the downloading via the mobile device.* | *Verify the website is online via the Rebel Server and able to be connected to and downloaded from via the mobile device.* | *The website hosted on the Rebel server needs to be created, online, and able to be connected to during the mobile device download.* |
| ***50.5*** | *Check the Rebel Server website can be connected to by anyone and the contents can be downloaded.* | *Verify the Rebel Server website is publicly available and the content can be downloaded.* | *Verify the Rebel Server website is available to the public and the contents can be downloaded.* | *The website hosted on the Rebel Server must be available for anyone to access and download the images from.* |
| ***50.6*** | *Verify Rebel Server can send Youtube url data to any user logged into a public website.* | *Verify a user logs in and can access the saved url link.* | *The user can view the Youtube url no matter the authentification.* | *The user can view the Youtube url before logging in and a secondary video after logging in.* |
| ***50.7*** | *Verify that a user with the correct ssh key pair can log into public website* | *ssh keypair is generated and shared with a test user. That user can login to the public website.* | *Any user with correct keypair can access the second video url and download images.* | *The mobile application can log into the public website and access the download images and second video.* |
| ***50.8*** | *Verify correct authentication to Rebel Server shows the second video.* | *A user with the correct key pair logs into the public website. Verify authenticated login plays second video.* | *Correctly authenticated user can access the second video.* | *The user Obiwan can view the second video and download images via the website.* |

***Constraint Test Plan***

| *Const No.* | *Test Method* | *Evaluation Method* | *Threshold* | *Objective* |
| --- | --- | --- | --- | --- |
| ***10*** | *Verify that no component of our transmission system uses Wi-Fi, Bluetooth, or Cellular Data* | *List all forms of data transmission and verify that Wi-Fi, Bluetooth, and Cellular Data are not included.* | *Wi-Fi, Bluetooth, and Cellular Data are not used for data transmission in any form.* | *Li-Fi system is used for all data transmission going out of the Empire Lab.* |
| ***20*** | *Verify that the total cost of all combined materials must be 300 USD or less.* | *Add up the total cost of all materials and ensure that the cost comes in at or below 300 USD.* | *Verify the cost of all materials is 300 USD or less.* | *The system can be fully assembled with the materials costing 300 USD or less.* |
| ***30*** | *Verify no electrical tethers are connected to the Empire Raspberry Pi.* | *Check that all external ports on the Empire Raspberry Pi are not connected to an external device.* | *No ports are connected to an external device.* | *The Empire Raspberry Pi transmits without any electrical tethers using Li-Fi.* |
| ***40*** | *Project is demonstrated in the last week of Fall 2024 semester.* | *The project is demonstrated by witnessing with a professor.* | *The demonstration takes place in the allotted time with a professor.* | *The project was successful during the last week of the Fall 2024 semester.* |
| ***50*** | *Verify that the measured distance between the Rebel Server and the Empire Pi is less than 5 meters.* | *Measure the distance between the Rebel Server and the Empire Raspberry Pi.* | *Measured distance must be more than 5 meters.* | *System is fully operational with the Rebel Server from at least 5 meters from the Empire Raspberry Pi.* |
| ***60*** | *Verify that the final demonstration is performed in the Russ basement.* | *Verify the room number where the demonstration takes place is in the basement of Russ.* | *Room number of the demonstration area is in the basement of Russ.* | *The project is performed successfully in the Russ basement.* |
| ***70*** | *Verify that the final demonstration components do not take more space than what is possible to be performed in the Russ basement.* | *Verify that the final demonstration components are operational and can be performed in the Russ basement.* | *Room number of the demonstration area is in the basement of Russ.* | *The project is performed successfully in the Russ basement.* |
| ***80*** | *Verify that the final group consists of 4+ members of different degree paths.* | *Count the number of members in the group and record each member's major.* | *The number of members must be greater than 3 and at least 4 different majors are included.* | *Group has 5 members of at least 4 different majors.* |
| ***90*** | *Verify that the ambient temperature does not limit the operational values of the system.* | *Verify the ambient room temperature does not prohibit the devices from operation.* | *The final system performs as specified in ambient temperatures of the basement of the Russ building.* | *The final system operates normally in the Russ building’s basement at ambient temperature.* |
| ***100*** | *Place each device on a scale to verify that it does not weigh more than 10 lbs.* | *Visually verify that the displayed weight on the scale does not exceed 10 lbs for each device.* | *Each device must not weigh more than 10 lbs as weighed by the scale.* | *Each device must weigh less than 10 lbs as measured by the provided scale.* |
| ***110*** | *Verify that all electrical devices can use the standard 120 VAC 60 Hz power supply.* | *Check that all electrical devices can use standard wall outlets for power.* | *All electrical devices are to use the standard 120 VAC 60 HZ wall outlets.* | *All electrical devices can be fully powered by the standard 120 VAC 60 Hz wall outlets.* |

**Standard Test Plan**

| *Standard* | *Test Method* | *Evaluation Method* | *Threshold* | *Objective* |
| --- | --- | --- | --- | --- |
| ***10*** | *Compare VLC system to* IEEE 802.11bb-23/0277rl |  |  | *System is functional while in compliance.* |
| ***20*** | *Comparison of group-created code to* Python PEP: 8. |  |  | *Code is functional while in compliance.* |
| ***30*** | *Verify OpenSSL encryption/decryption adheres to* Federal Inf. Process. Stds. (NIST FIPS) - 197-upd1 |  |  | *encryption/decryption is functional while in compliance.* |
| ***40*** | *Comparison of group-created code to* ISO/IEC 9899:2024 |  |  | *Code is functional while in compliance.* |
| ***50*** | *Verify that all of the group hashes follow the* FIPS PUB 180-4: Secure hash standard |  |  | *Hashes are correct while complying.* |
| ***60*** | *Verify all wireless traffic adheres to HTTPS* | *Evaluate the contents of a sent packet and verify data follows HTTPS* | *Packet is organized using HTTPS* | *packets can be sent and received successfully by Rebel server* |
| ***70*** | *Verify the transmitted images adhere to the* ISO/IEC 15948:2003 (E) | *Check the metadata of an image to ensure it retains PNG standard compliance after transmission.* | *Image metadata is compliant with the PNG standard.* | *All 10 transmitted images in our system retain PNG metadata.* |
| ***80*** | *Ensure laser diode usage falls within the* ANSI Z136 standards. |  |  | *Don’t shine lasers in people’s eyes, or look directly into the laser.* |
| ***90*** | IETF RFC8017 RSA Cryptography Specifications | *Verify that the created RSA keys follow specifications* | *The RSA keys can be assigned for authentication* | *The RSA keys successfully authenticate* |

***Requirement 10*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: A spreadsheet will be maintained of all parts bought by the team and added together in said sheet. The total gathered from this sheet will then be subtracted from the $300 maximum budget. The threshold is the bought items being less than $300 and the objective is as low as possible with all system functions.*

***Requirement 10.1*** *will be tested in Russ Basement, where we will implement the Li-Fi system. The test method is as follows: Two Li-Fi transceivers will be set up 5 meters across from each other. A test set of data will be used to observe light being used for transmission as well as receiving accurate data post-transmission. The threshold for this test is for the data being sent to be the same hex value as the data received using a VLC system. The objective for this test is for the transmission speed to be greater than 1Gb/s.*

***Requirement 10.2*** *will be tested in Russ Basement which is where we will be verifying that no data was lost during the transmission process. The test method is as follows: Before and after the transmission process the md5sum hash will be taken and then after the transmission is complete the two hashes will be compared. They should then match verifying that the data was successfully sent losslessly. The threshold for this test is it should be completed with no lost data and the objective is also no lost data during transmission.*

***Requirement 10.3*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Two Raspberry Pi’s connected to 5V power will be turned on. The threshold for this test is for both Pi’s will show visual stimuli to show operational. The objective for this test is for both Raspberry Pi’s to be able to run test code to prove fully operational.*

***Requirement 10.4*** *will be tested in Russ Basement, where the system will be assembled for testing. The test method is as follows: Two Raspberry Pi’s will be configured each with a laser and a solar cell to send and receive data. They each should have the capability to send and receive data independently. The threshold for this system is for both Pi’s to be able to both send and receive data. The objective of this system is for both Raspberry Pi’s to be able to independently send and receive data losslessly.*

***Requirement 10.5*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: All code relating to the transceiver system will be analyzed for the approved coding languages. The threshold for this test is for all code to be used to be either Python, C, or C++. The objective for this test is for all of this code to compile with no errors before being implemented.*

***Requirement 10.6*** *will be tested in Russ Basement which is where the system will be assembled for testing. The test method is as follows: The Empire Raspberry Pi will have a directly attached USB and it can successfully download the files from the USB to the Empire Raspberry Pi. The threshold for this test is for the Empire Raspberry Pi to successfully download files from the USB. The objective of this test is for the Empire Raspberry Pi to losslessly download all files from the USB drive to the Empire Raspberry Pi.*

***Requirement 10.7*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: Two Raspberry Pi’s will be set up for Li-Fi transmission. Each Raspberry Pi will send one image and receiver one image. The image that is received from each Raspberry Pi will be opened in the Raspberry Pi operating system. The threshold for this test is for the post-transmission image on both Raspberry Pis to have the same file format as the image pre-transmission. The objective for this test is for all of each post-transmission image to show the file format at the beginning of its text representation.*

***Requirement 10.8*** *will be tested in Russ Basement which is where the system will be assembled for testing. The test method is as follows: The two Raspberry Pi’s can successfully communicate using the laser and solar cell configuration without any obstructions blocking the path of the laser. The threshold for this test is for the laser to successfully send a beam of light to the receiving Raspberry Pi’s solar cell. The objective for this test is for all of the data to be transmitted between the two Raspberry Pis without the laser path being obstructed.*

***Requirement 10.9*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: The Li-Fi transceiving system will be set up for operational use in the Russ Basement. During transmission, the voltage readings from the Raspberry Pi’s, to their respective Li-Fi system, will be recorded. The threshold for this test is for the voltage readings recorded to be within 5% of the 5V goal. The objective for this test is for all voltage readings to be as close to 5V as possible.*

***Requirement 10.10*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: Both transceiving systems take in 5V from their respective Raspberry Pi. The voltages will be measured during the test and monitored throughout to ensure proper power to complete the processes. The threshold for this test is that the Empire and Rebel transceiving systems take in* 5V±5% *from respective Raspberry Pi’s. The objective for this test is that the Empire and Rebel transceiving systems can take in 5V from their respective Raspberry Pis.*

***Requirement 20*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: The Li-Fi transceiving system will be set up for operational use in the Russ Basement. Before data is transmitted it will be encrypted using symmetric key AES-256 encryption. After transmission, the data will be decrypted using the same key and AES-256. The threshold for this test is for the data to change after being encrypted and for the post-decryption text to be binary equal to the pre-encryption text. The objective of this test is for all transmitted data to be successfully encrypted and decrypted.*

***Requirement 20.1*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: The data binaries will be compared to ensure that they are the same before and after transmission. The threshold for this test is for the data binaries to be the same before and after transmission. The objective for this test is for the data binaries to be the same before and after all transmissions.*

***Requirement 20.2*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: A test text file will be created with a random string. This file will then be encrypted using AES-256 with a given key. The same file will then be decrypted with the same key. The threshold for this test is for the data to change after being encrypted and for the post-decryption text to be binary equal to the pre-encryption text if the same key is passed to the algorithm. The objective for this test is for all transmitted data to be successfully encrypted and decrypted using this same key.*

***Requirement 20.3*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows:* A password will be shared with only group members for encryption and decryption verification and *all group members know the password key. The threshold for this test is that all group members know the password key. The objective of this test is for each group member to enter the correct password to encrypt and decrypt the data.*

***Requirement 20.4*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: The Empire Raspberry Pi will encrypt a test message and transmit the message to the Rebel Raspberry Pi. This message will then be decrypted by the Rebel Raspberry Pi. The plaintext of the decrypted message must be binary equal to the plaintext of the pre-encryption message on the Empire Raspberry Pi. The threshold for this test is for the message data of the decryption text to be binary equal to the pre-encryption text after being transmitted. The objective for this test is for all transmitted data to be equal to the pre-encryption plaintext and be decrypted.*

***Requirement 30*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Verify an uploaded picture can be processed via the application. The threshold for this test is for the image evaluation to occur using PNG images. The objective of this test is for the image evaluation application to be able to process images for specific data points.*

***Requirement 30.1*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Verify image evaluation software can correctly identify 10 Death Star images out of 100. The threshold for this test is for the image evaluation process to be able to identify the correct 10 images containing red circles out of 100 possible images. The objective of this test is for the image evaluation program to be able to scan, process, and identify 10 images out of 100 that contain red circles.*

***Requirement 30.2*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Verify that all 100 images from the USB are copied onto the Empire Raspberry Pi. The threshold for this test is for all 100 images to be accessed and uploaded onto the Empire Raspberry Pi for image evaluation. The objective of this test is to confirm that all 100 images are accessed, copied, and prepared for image evaluation.*

***Requirement 30.3*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Both Raspberry Pi’s storage will be analyzed to verify that only the Empire Raspberry Pi can execute the image evaluation application. The application will then be executed on the Empire Raspberry Pi using 100 test .png images. The threshold for this test is for all 100 images utilized by the Empire Raspberry Pi image evaluation application. The objective for this test is for all 100 images to be accessed by only the Empire Raspberry Pi image evaluation application when executed.*

***Requirement 40*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: A hash will be generated for a set of 10 test .png images. A script will then be created to generate hashes of the same images. The hashes generated from both the script, and hashing the images directly, must be binary equal. The threshold for this test is for the two techniques of generated hashes to be binary equal. The objective for this test is for all 10 images being transmitted can have their hashes generated by this script.*

***Requirement 40.1*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Verify that there is accurate data transmission confirmation of md5 sums that were compared using a Linux data verification script. The threshold for this test is for the confirmation of accurately transmitted data to be done by comparing md5 sums using a Linux data verification script. The objective of this test is to create a Linux data verification script that compares md5 sums for accurate data transmission confirmation.*

***Requirement 40.2*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: Verify that the comparison of the md5sums is done on the Empire Raspberry Pi, only after the transmission is completed. The threshold for this test is for the comparison of md5sums to be performed on the Empire Raspberry Pi after the transmission is completed. The objective for this test is for a matching comparison of the md5sums after transmission is completed, on the Empire Raspberry Pi.*

***Requirement 40.3*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: 10 test .png images will be transmitted by the Empire Raspberry Pi, to the Rebel Raspberry Pi. Each transmitted image will have its md5sum hash values generated and saved. These md5sum values will then be transmitted back to the Empire Raspberry Pi. The threshold for this test is for all 10 md5sums transmitted by the Rebel Raspberry Pi to get back to the Empire Raspberry Pi. The objective for this test is for all 10 images being transmitted can have their hashes returned to the Empire Raspberry Pi for comparison.*

***Requirement 50*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: Verify the mobile device has an application to evaluate the weaknesses of the Death Star plans. The threshold for this test is for the mobile application to be able to evaluate the weaknesses of the Death Star plans. The objective of this test is for the mobile application to be able to evaluate each image for the weaknesses depicted within the red circles.*

***Requirement 50.1*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Ensure that the evaluation program creates a scrollable table to display the evaluated weaknesses. The threshold for this test is to confirm that the evaluation program creates a scrollable table to display the evaluated weaknesses. The objective of this test is for the mobile weakness evaluation application to create a scrollable table and display all of the weaknesses.*

***Requirement 50.2*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: The mobile application will use 10 test .png images with various red circles to depict potential weaknesses. The mobile application will then be run on these test images. The threshold for this test is to verify that the mobile application saves the data of each red circle for all of the 10 images. The objective of this test is for the mobile weakness evaluation application to evaluate the weaknesses of all of the transmitted Death Star images when downloaded from the Rebel Server.*

***Requirement 50.3*** *will be tested in the Russ Basement which is where the system will be assembled for testing. The test method is as follows: Ensure that each weakness depicted by the red circles is shown only once on the scrollable table. The threshold for this test is to verify that each depicted weakness is shown only once on the scrollable table. The objective of this test is for the scrollable table to show all depicted weaknesses only once.*

***Requirement 50.4*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Verify the website is online and able to be connected during the downloading via the mobile device. The threshold for this test is to verify the website is online via the Rebel Server and able to be connected to and downloaded from via the mobile device. The objective for this test is for the website hosted on the Rebel server to be created, online, and able to be connected to during the mobile device download.*

***Requirement 50.5*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Verify that the Rebel Server website is publicly available and the content can be downloaded. A test user with the correct ssh keypair is created and logged onto the public website. The threshold for this test is to verify the Rebel Server website is available to the public and the contents can be downloaded. The objective for this test is for the website hosted on the Rebel Server must be available for anyone to access and download the images from.*

***Requirement 50.6*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Verify that the Rebel Server website is publicly available and access the site via a test user. The threshold for this test is for the user to be sent the url for the first Youtube video with no access to the secondary video. The objective for this test is for the website hosted on the Rebel Server to send the video to the mobile application user.*

***Requirement 50.7*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Verify that the Rebel Server website is publicly available and the content can be downloaded. A ssh keypair will be generated on the Rebel Server and the public key will be shared with a test user. This user will then log in to the website. The threshold for this test is to verify the Rebel Server website is available to the public, the contents can be downloaded, and the user is sent the url for the secondary Youtube video. The objective for this test is for the website hosted on the Rebel Server to authenticate the mobile application user and allow the user to download images and access the second video url.*

***Requirement 50.8*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: A test user logs into the public website with correct keypair. The website allows the user to show the second video. The threshold for this test is to verify that the correctly authenticated user can view the second video and download the images from the Rebel Server. The objective for this test is for the website hosted on the Rebel Server must be available for only the authenticated user, Obiwan Kenobi, to access the second full video and images from the Rebel Server and download the images.*

***Constraint 10:*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: List all forms of data transmission and verify that Wi-Fi, Bluetooth, and Cellular Data are not included. The threshold for this test is for Wi-Fi, Bluetooth, and Cellular Data to not be used for data transmission in any form. The objective of this test is to use the Li-Fi system for all data transmission going out of the Empire Lab.*

***Constraint 20:*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Add up the total cost of all materials and ensure that the cost comes in at or below 300 USD. The threshold for this test is to verify the cost of all materials is 300 USD or less. The objective for this test is for the system to be fully assembled with the materials costing 300 USD or less.*

***Constraint 30:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Check that all external ports on the Empire Raspberry Pi are not connected to an external device. The threshold for this test is for no ports to be connected to an external device. The objective of this test is for the Empire Raspberry Pi to transmit without any electrical tethers using Li-Fi.*

***Constraint 40:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: The project is demonstrated by witnessing with a professor. The threshold for this test is for the demonstration to take place during the allotted time with a professor. The objective for this test is for the project to be successful during the last week of the Fall 2024 semester.*

***Constraint 50:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Measure the distance between the Rebel Server and the Empire Raspberry Pi. The threshold for this test Measured distance must be more than 5 meters. The objective for this test is for the system to be fully operational with the Rebel Server at least 5 meters from the Empire Raspberry Pi.*

***Constraint 60:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Verify the room number where the demonstration takes place is in the basement of Russ. The threshold for this test is for the Room number of the demonstration area in the basement of Russ to be correct. The objective for this test is for the project to be performed successfully in the Russ basement.*

***Constraint 70:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method follows: Verify that the final demonstration components are operational and can be performed in the Russ basement. The threshold for this test is for the Room number of the demonstration area to be in the basement of Russ. The objective of this test is for the project to be performed successfully in the Russ basement.*

***Constraint 80:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Count the number of members in the group and record each member's major. The threshold for this test is for the number of members must be greater than 3 and at least 4 different majors are included. The objective of this test is for the Group to have 5 members of at least 4 different majors.*

***Constraint 90:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Verify the ambient room temperature does not prohibit the devices from operating. The threshold for this test is for the final system to perform as specified in ambient temperatures of the basement of the Russ building. The objective for this test is for the final system to operate normally in the Russ building’s basement at ambient temperature.*

***Constraint 100:*** *will be tested in Room SC 007 which is where we will be planning and documenting next semester. The test method is as follows: Visually verify that the displayed weight on the scale does not exceed 10 lbs for each device. The threshold for this test is that each device must not weigh more than 10 lbs as weighed by the scale. The objective of this test is that each device must weigh less than 10 lbs as measured by the provided scale.*

***Constraint 110:*** *will be tested in the Russ Basement, where the system will be assembled for testing. The test method is as follows: Check that all electrical devices can use standard wall outlets for power. The threshold for this test is for all electrical devices to use the standard 120 VAC 60 HZ wall outlets. The objective for this test is for all electrical devices to be fully powered by the standard 120 VAC 60 Hz wall outlets.*

***Standard 10:*** *will be verified under* IEEE 802.11bb-23/0277rl and will be tested in room SC 007. The test method is as follows: *Compare the VLC system to* IEEE 802.11bb-23/0277rl and ensure that all of the requirements are valid. The threshold for this test is that all components of the VLC systems fall within these standards. The objective for this test is for the VLC system to be fully functional while staying within the standards.

***Standard 20:*** *will be verified under Python PEP: 8 and will be tested in room SC 007. The test method is as follows: Gather all Python code created for this system and compare it with the requirements specified in the PEP: 8. The threshold for this test is that all code falls within these standards. The objective for this test is for the code to be functional while within said standard.*

***Standard 30:*** *will be verified under (NIST FIPS) - 197-upd1 and will be tested in room SC 007. The test method is as follows: Verify that the OpenSSL instance of AES is compliant with this standard through observation. The threshold for this test is that all implementation of AES falls within these standards. The objective for this test is for encryption/decryption to be functional while within said standard.*

***Standard 40:*** *will be verified under ISO/IEC 9899:2024 and will be tested in room SC 007. The test method is as follows: Gather all C/C++ code created for this system and compare it with the requirements specified in the ISO/IEC 9899:2024. The threshold for this test is that all code falls within these standards. The objective for this test is for the code to be functional while within said standard.*

***Standard 50:*** *will be verified under FIPS PUB 180-4 and will be tested in room SC 007. The test method is as follows: Verify that the groups hashes that are sent between both Raspberry Pis follow the secure hash standard FIPS PUB 180-4. The threshold for this test is that all hashes fall within these standards, The objective for this test is for all hashes to be correct and functional while falling within the standard.*

***Standard 60:*** *will be verified under HTTPS and will be tested in the Russ Basement. The test method is as follows: Use Scapy to analyze the hex contents of a packet going to the Rebel Server. Verify that this packet is organized to what is specified in HTTPS. The threshold for this test is that all packets received and sent follow this standard. The objective for this test is for all packets to follow HTTPS going to and from the Rebel Server.*

***Standard 70:*** *will be verified under ISO/IEC 15948:2003 (E) and will be tested in the Russ Basement. The test method is as follows: Use the tested Li-Fi transceiver system to transmit a single test .png image. Take the hex value of this image and verify the data is organized in accordance with the standard. The threshold for this test is that the image transmitted follows this standard. The objective for this test is for all 10 images transmitted in the system to follow the standard.*

***Standard 80:*** *will be verified under ANSI Z136 and will be tested in the Russ Basement. The test method is as follows: Observe the Fi-Fi transceiver system and verify its compliance with all specifications of the standard. The objective of this test is to verify all safety specifications are followed at all times.*

***Standard 90:*** *will be verified under IETF RFC8017 and will be tested in Russ Basement. The test method is as follows: Observe and verify that the created RSA keys follow specifications. The threshold for this test is that the RSA keys can be assigned for authentication. The objective for this test is for the RSA keys to successfully authenticate the user.*

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