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March 13, 2014
Dr. Andrew Rawicz
School of Engineering Science
Burnaby, BC V5A 1S6

Re: ENSC 440W / ENSC 305W Capstone Project: Design Specifications for SkySeed

Dear Dr. Rawicz,

Panalloon Systems is pleased to submit “*Design Specifications for SkySeed”* for our ENSC 440 Capstone Project. Our intent is to develop and implement an economical but effective solution for commercial aerial surveillance problems. Such solutions are in demand by law enforcement and security agencies, as well as agriculture, environmental, and research industries.

This document details the technical designs that members Panalloon Systems have developed to achieve SkySeed’s functional requirements. The body of this document describes the necessary system level designs SkySeed is comprised of. For the purpose of recreation, the low level implantation of each system is outlined in the appendix portion. To further reaffirm SkySeed’s functionality, test plans are also enclosed in the appendix.

Panalloon Systems is delivering this document to have you and your respective staff on board with design/development process of the SkySeed model. Should you have any questions or concerns about our design specifications, do not hesitate to contact us at (778) 558-0082 or by email at panalloon-440@sfu.ca.

Sincerely,

Amir Shamsuddin

Chief Executive Officer
Panalloon Systems

Enclosure: Design Specifications for SkySeed

March 13th 14

P Λ N Λ L L O O N

Design Specifications for SkySeed

Prepared for

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Abstract

In maintaining outdoor surveillance, one must design for outdoor purposes and conditions. The principle design behind SkySeed's outdoor surveillance system is a mobile controllable camera at a high vantage point (20 to 30 meters) with real-time video feed. This concept goes hand-in-hand with a reliable design for user mobility and interaction.

The proof-of-concept of the SkySeed model is divided into five high level systems: *Aerial System, Power System, Motion System, Wireless Network* and *Software*. The design process of each system is developed independently and in parallel. The aerial system is primarily aimed at lifting a 1.59 kg payload which is acquired by utilizing a 1.67 m diameter helium balloon. The power system must keep SkySeed's electronics supplied with the appropriate voltages and currents while fully protecting them from current spikes and unnecessary noise. The power system is designed to be fully self-sustainable in the prototyping phase. The motion system is implemented via two actuators to provide two Degrees of Freedom (DOF). Through Wi-Fi communication, the two actuators control the vertical dip and the azimuth motion of the surveillance camera. The wireless network provides communication for motion, as well as the video stream transmission to a base station. SkySeed's software is the primary control of the overall system and the main source of feedback to the user.

While testing both discreetly and as an integrated unit, testing cycles will take place to ensure that SkySeed meets all system requirements. Testing discretely aims to find problems at an early stage and facilitate design changes. Results are used toward SkySeed's progressive and reiterative design process.

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Glossary

CAD: Computer Aided Design
PWM: Pulse Width Modulation
FBD: Free Body Diagram
DOF= Degrees of Freedom
UI = User Interface
WLAN = Wireless Local Area Network
IP = Internet Protocol
SPI = Serial Peripheral Interface
LAN = Local Area Network
TCP = Transmission Control Protocol
UDP = User Datagram Protocol
WPA2 = Wi-Fi Protected Access II
WEP = Wired Equivalent Privacy
CGI = Common Gateway Interface
HTTP = Hypertext Transfer Protocol
GPIOs = General-Purpose Input Outputs

1 Introduction

The amount of security for an outdoor event is often limited due to cost. As the event gets larger the cost increases and often security measures are overlooked. SkySeed is a real-time outdoor surveillance system attached to a helium weather balloon that is tethered at an elevation of 20-30 meters. Through a graphical user interface, the operator at a base station can observe and change the area of interest of the video feed. Figure 1.1 portrays the SkySeed model at a proof-of-concept level.

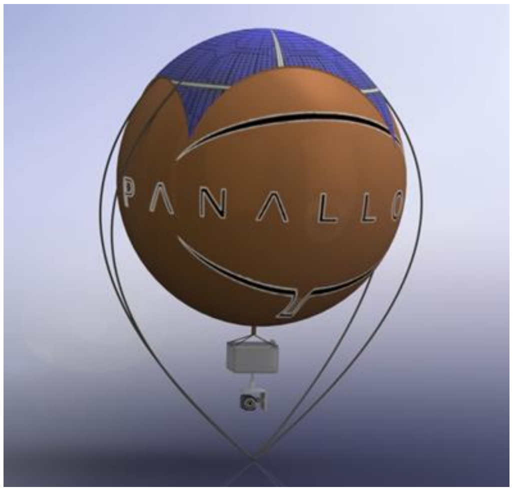


Figure 1.1: 3D Rendering of SkySeed's proof-of-concept

SkySeed is comprised of five subsystems that are designed and developed in parallel. Together, the software, wireless network, aerial, motion and power system, ensure the reliability and completeness of the SkySeed design.

This document outlines the design specifications necessary to achieve a proof-of-concept for SkySeed. It should be noted that this design will incorporate all the basic features of [1] Functional Specifications for SkySeed and may not include all the features of a fully implemented prototype or production version.

The notation **[R-p-n]** references the functional specification, where **R** denotes the functional requirement, **n** represents the requirement number, and **p** indicates that the requirement is necessary for:

A. Proof-of-concept
B. Prototype
C. Production model

1.1 Intended Audience

The design specifications are to be used by all members of Panalloon Systems during the design, development and testing stages of SkySeed. This document will be used as general design guidelines during the proof-of-concept, prototype and production model implementation. Furthermore, technical details and measurement data will be utilized as developing benchmarks.

2 System Overview

Panalloon Systems' main goal is to provide high-end technology at an affordable price. In this document, we present SkySeed: an outdoor aerial surveillance system. The purpose of SkySeed is to enable the user to access a real-time panoramic view of their target surroundings. With this product, the user will be able to have a reliable surveillance system that will last up to eight hours. The operating time is not limited to day or night, which allows the user to select their desired operating hours. The base station will empower the operator with a user friendly UI, which includes the functionality to observe and alter the view obtained from the video stream.

SkySeed is an integration of multiple systems that together create a reliable and cost effective product. The aerial, motion and power systems along with the wireless network and software components constitute the core of SkySeed. Figure 2.1 below shows a basic diagram depicting the individual component that make up SkySeed.

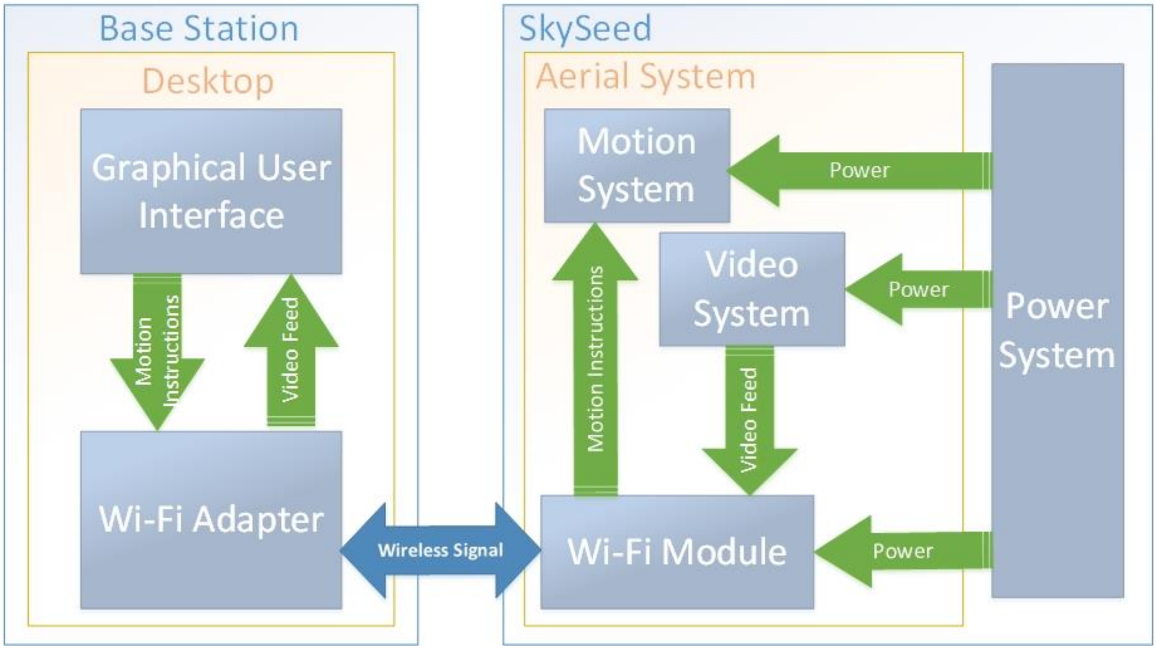


Figure 2.1: Block diagram depicting SkySeed's individual components

The aerial system lifts SkySeed to the desired height. The motion system works with the wireless network component to deliver the desired view to the UI. SkySeed is enriched with sophisticated software to move the camera wirelessly from a user interface at the base station. The signals sent from the router at the base will be received by the Wi-Fi-Shield and used to control the motion of the camera. Lastly, Powering SkySeed will be achieved by a reliable powering system at the base station. The system electronics will be powered using a 12-volt battery and a power cable. These five components will be thoroughly described in subsequent sections.

2.1 Fault Tree Analysis

Fault tree analysis is a prime method of demonstrating the system overview and system safety analysis. If correctly developed, this fault tree can be used to illustrate and predict the most likely causes of system failure. The fault tree developed in Figure A.1 demonstrates various possible events that may occur in the SkySeed system and their respective origins.

3 Aerial System

This section outlines mechanisms that form the aerial system and it also details their importance for SkySeed's functionality. Figure 3.1 illustrates the main components of the aerial system: a helium balloon, a netting, an electronic enclosure, a parachute, and a tetherline.

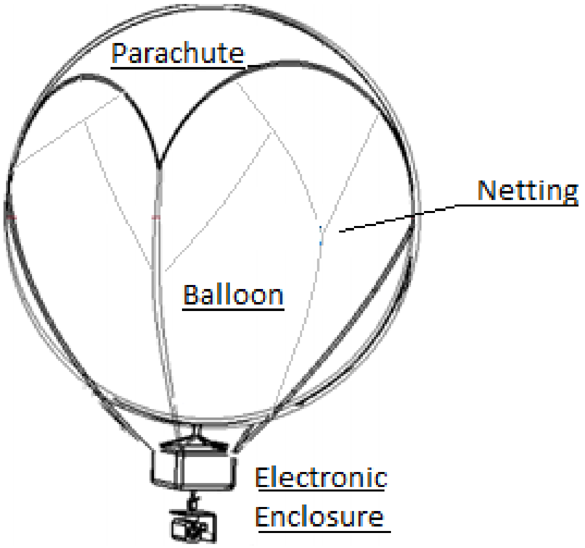


Figure 3.1: CAD drawing showing the netting around the balloon

3.1 Netting

To ensure the helium balloon is long-lasting, the payload must be distributed over the balloon membrane evenly [2]. A netting system which wraps around the balloon will not only distribute the load evenly, but it will also act as a mechanism to attach the enclosure to the balloon. Figure 3.2 elaborates on the design and dimensions of the netting.

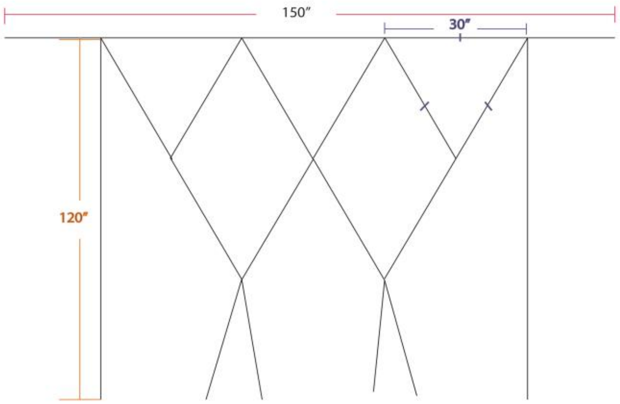


Figure 3.2: Measurements used to construct netting

3.2 Balloon

The key aspects of the aerial system is utilizing the lifting capabilty of the chloroprene weather balloon to lift a payload. Summarized in Table 3.1 are the mass of the electronics, mechanical components, and cables which are crucial to SkySeed's operation.

Table 3.1: Weight of the Components Associated with SkySeed

Component Name	**Mass (g)**
Arduino UNO	28
WiFi Shield	58
2 x LS 3006 Servo	88
WANSCAN IP Camera	620
Enclosure	175
Mechanical Components	271
Cables (Tether & Power Line)	300
1.67 m Chloroprene Balloon	50
Total	**1590**

Based on the total mass, the helium ballon is required to have a minimum lifting capability of 1590 g. The amount of helium required to lift this payload can be calculated through Archimedes' principle of buoyancy as

$$F_L = (\rho_{air} - \rho_{He})gV - mg, \tag{3.1}$$

where F_L is the net lifting force, ρ_{air} is density of air, ρ_{He} is the density of helium, g is the acceleration due to gravity, V is the volume of helium required, and m is the total mass of SkySeed [2]. Figure 3.3 shows the free body diagram of the helium balloon.

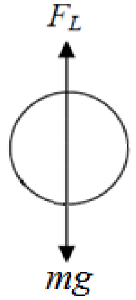


Figure 3.3: FBD of the SkySeed

Using equation (3.1) and the values from Table 3.2, the minimum required amount of helium is 1.42 m^3. The most economically viable balloon size available on the market is a 1.67 m chloroprene balloon [3]. It can hold up to 2.46 m^3 of helium and has an approximate lift of 1.86 kg which is well over the required lift of 1.59 kg.

Table 3.2: Predetermined Values and Constants

ρ_{He} (kg/m^3) at 0 °C	ρ_{air} (kg/m^3) at 0 °C	g (m/s^2)	m (g)
0.164	1.292	9.81	1590

In order to lift the required weight, the balloon is gradually filled with helium using a regulator attached to a helium tank. Once the balloon has been filled and securely fastened, it remains inflated for up to 5 days. This is due to the helium permeability property of the chloroprene material [5].

3.3 Stability

When considering stability for a tethered balloon it can be assumed, for design purposes, that in a constant wind flow the tethered balloon will be blown down to a certain angle with respect to the vertical axis. This effect is depicted in Figure 3.4. Eventually the affecting forces will reach equilibrium such that the balloon will remain in position. Assuming that acceleration forces are negligable, drag force F_D, tether force F_T, and net lift force F_L are the three forces acting on the balloon [4]. As a result, increasing the net lift force will increase the stability (more tension being applied on the cables means drag force must be stronger to move the balloon).

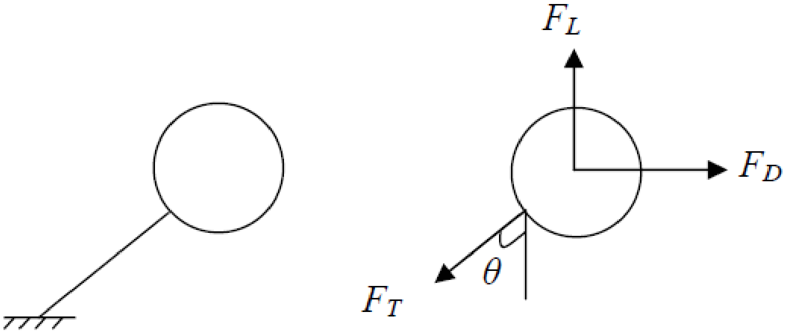


Figure 3.4: Pascal's Law for a square solid and for a sphere

Using Archimedes' principle of buoyancy, the buoyant force of a spherical balloon takes the form

$$F_b = \frac{4}{3}\pi r^3 \rho_{air} g\ , \qquad (3.2)$$

where r is the radius of the balloon. The net lift of F_L is the buoyancy force F_b subtracted by both the weight of the balloon and injected helium. This can be written as

$$F_L = F_b - \frac{4}{3}\pi r^3 \rho_{He} g - mg \qquad (3.3)$$

The drag force F_D on a stationary and fixed sphere which is subjected to a fluid flow is

$$F_D = \frac{1}{2} C_D \rho_{air} \mu^2 \pi r^3, \qquad (3.4)$$

where C_D is the drag coefficient of the system and μ is the wind speed. The vector resultant force F_T applied on the tether line can be calculated as

$$F_T = \sqrt{{F_L}^2 + {F_D}^2} \qquad (3.5)$$

According to the functional specification [R-26-A], the balloon must withstand 15 km/h (4.17 m/s) windspeeds. Using equations (3.2) through (3.5) and values from Table 3.2 and Table 3.3, the tensional force applied to the cables is calculated to be 16.19 N. With a 20 lbs. (88.9 N) test line (fishing line), SkySeed will be safely secured to the ground. These results are sumarized in Table 3.4.

Table 3.3: Predetermined Values and Constants [3]

r (m)	μ (m/s)	C_D
1.67	4.17	0.7

Table 3.4: Calculated Forces and Tensions Acting on SkySeed

F_b (N)	F_L (N)	F_D (N)	F_T (N)
30.91	11.78	11.11	16.19

3.4 Parachute Design

Since SkySeed is lifting expensive electronics to an elevated position, considerable design will be put into keeping these components safe in an event of free-fall or dislodgment of electronics from the helium balloon. The prime approach in implementing this safety mechanism is a deployable parachute attached to the electronic casing. According to [7], electronic equipment can handle 40 g (392 m/s^2) without physical damage. Using Newton's 4th equation of motion

$$v_{final}{}^2 = v_{impact}{}^2 + (2 * a * s), \tag{3.6}$$

where $a = -40\ g$, and s represents the displacement of exoskeleton thickness (0.5 cm). The velocities v_{impact} and v_{final} represent the initial velocity upon impact and the final velocity respectively. Calculations below shows velocity threshold that causes zero damage

$$v_{final} = 0\ m/s\ ,$$

$$v_{impact} = 2 * a * s\ = 1.98\ m/s \tag{3.7}$$

In parachute designing, it is important to estimate a drag force that can bring the free-falling object to a desired terminal velocity prior to collision. The parachute drag force F_d is expressed as

$$F_d = {}^1/_2\, \rho_{air} * C_d * A * v^2\ , \tag{3.8}$$

where A represents parachute surface area to be calculated, ρ_{air} is 1.292 kg/m^3, and C_d (approximately 1.5) is the drag coefficient for a dome shaped parachute [6]. The force of gravity F_g is

$$F_g = m * g\ = 1.590\ kg * 9.81\ \ m/s^2 = 15.59\ N, \tag{3.9}$$

To attain terminal velocity the drag force must equate the free-falling weight

$$F_g = F_d\ \ , \tag{3.10}$$

$$F_g = {}^1/_2\, \rho_{air} * C_d * A * v^2\ . \tag{3.11}$$

The area of the parachute can therefore be solved as

$$A = \frac{2 * m * g}{\rho * C_d * v^2} = \frac{2(15.59)}{(1.292)(1.5)(3.92)} = 4.11\ m^2 \tag{3.12}$$

Using this value of v_{impact} in (3.7), as well as in (3.12), the diameter d of the parachute is calculated as

$$d = 2 * \sqrt{{}^A/_\pi} = 2.28\ m \tag{3.13}$$

Figure 3.5 displays a model of the parachute of 3.02 meter diameter intended for SkySeed's prototype model.

Figure 3.5: Model of parachute, adapted from [8]

4 Power System

This section describes the mechanisms that make up the power system. The main purpose of this system is to provide power to all of SkySeed's electronics in a safe and reliable manner. This power system is composed of a rechargeable battery, circuit protection mechanisms, and a voltage regulating network. Detailed in Table4.1 are the various voltage and current requirements of all the electronics associated with SkySeed.

Table 4.1: Voltage and Current Requirements for SkySeed's Electronics

Device	Voltage (V)	Max Current Draw (mA)	Power (W)
WANSCAM IP Camera	12.0	83.3	1.0
Arduino UNO and Wi-Fi Shield	5.0-12	250	1.25
LS 3006 (Top)	4.0-6.0	300	1.50
LS 3006 (Side)	4.0-6.0	500	2.50

The total maximum current drawn by all the electronic devices is 1.13 A and the desired operating time from functional requirement [R-49-B] is at least 8 hours which implies the system requires a power source that can sustain at least 9.04 Ah. A Panasonic rechargeable battery that is capable of supplying 12 V and 12 Ah was chosen as the main power source for the SkySeed proof of concept (as it satisfies the highest voltage requirement and can sustain the current drawn well over 9.04 Ah). It was decided that a direct power connection between the battery and video camera is the most appropriate as they are both compatible and it also removes the need for a voltage regulator. Since the operating voltage of the Arduino and servos can vary, it is desirable to set them to a fixed voltage of 5 V. This removes the need for additional regulators which are not 100% efficient [9]. Figure 4.1 is an electrical schematic of the power system which details the component layout and connections.

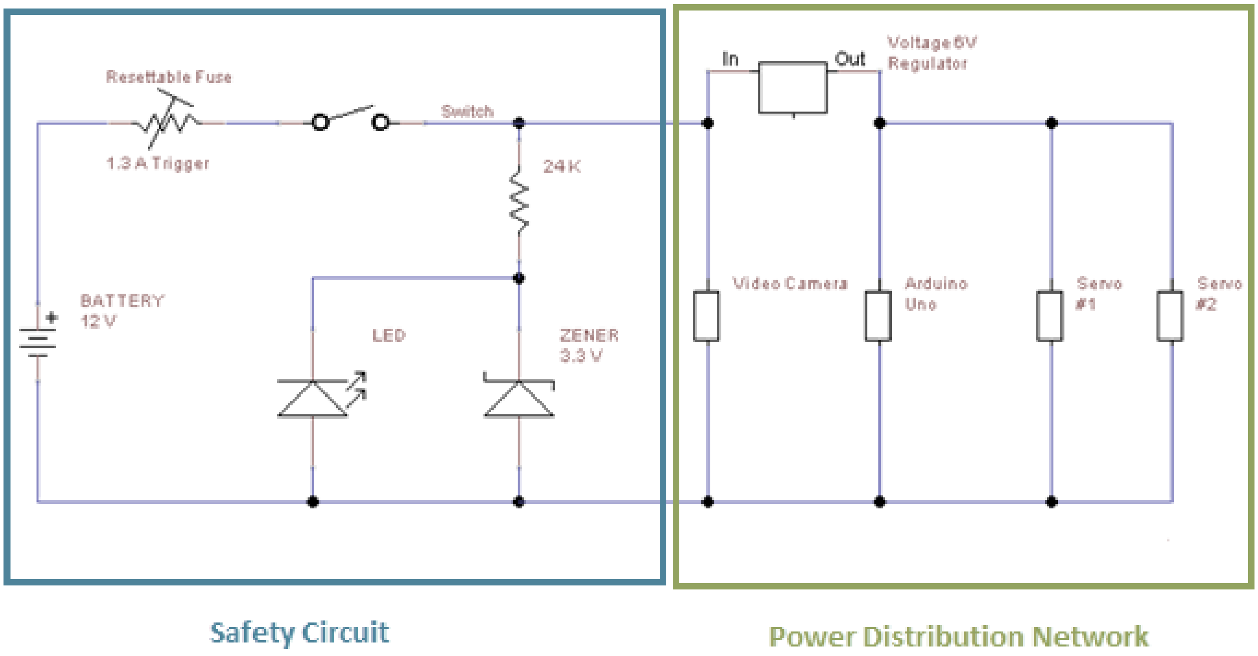


Figure 4.1: Power system schematic

Aside from meeting the voltage and current requirements of the electronics, another great concern regarding this system is the safety issue of using a 12 V / 12 A battery. This battery has the capability of dissipating a great amount of energy in a short amount of time which can be hazardous if not handled properly. Figure 4.2 is a 3D rendering of the power system's enclosure along with its connectors. This system incorporates four mechanisms to ensure the safety of primarily the users, and also the electronics:

1. A fuse that cuts the power at the battery if too much current is drawn
   - The fuse that is used is a Bourn's MF-065 which triggers at 1.3 A. After the fuse is triggered it will go into high impedance mode and cut off any power from being delivered to the main circuitry preventing any further damaged
2. A switch to cut off the power to SkySeed's electronics from the battery
   - The switch enables the user to cut off power in an event of an emergency or simply when it is not being use. This switch also has an LED which indicates to the user whether the line is live or not.
3. An enclosure that restricts access to the users from the power circuitry
   - The enclosure acts as safety measure to users by restricting their access to the power circuitry. It also doubles as mechanism to protect the circuitry from the environment.
4. Connectors that limit user access
   - Another safety feature is the use of coaxial ports that prevent the pins from contact with any users and also from metallic material shorting out the wires.

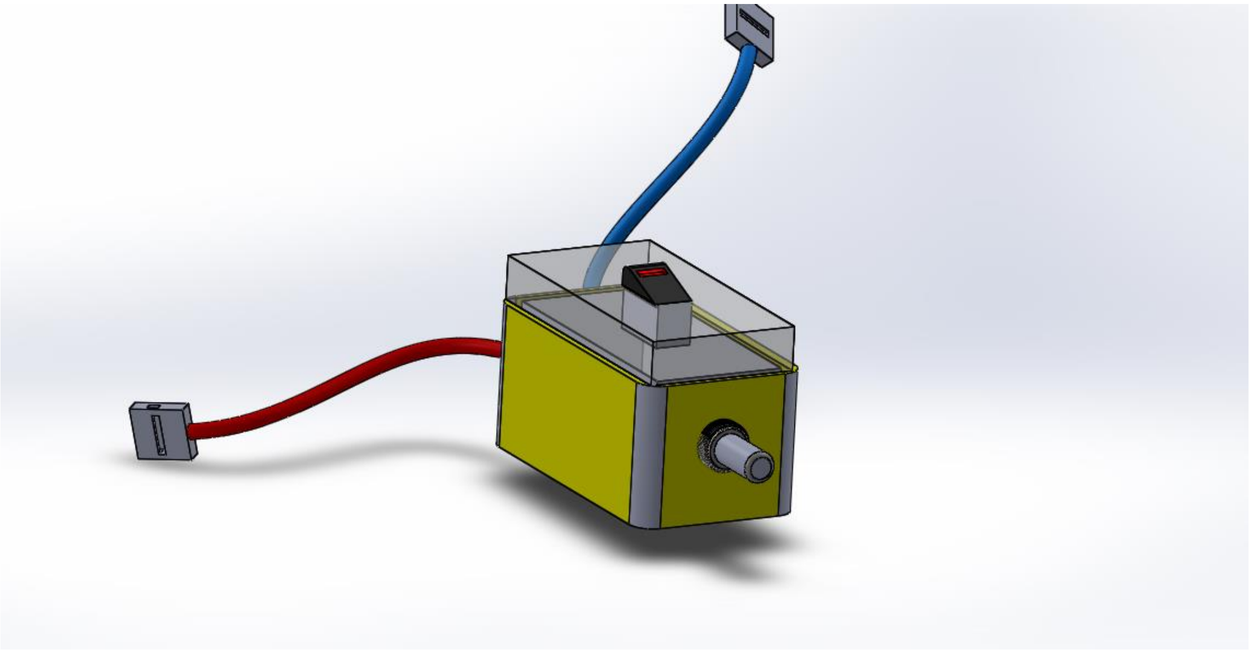


Figure 4.2: 3D rendering of power system enclosure

5 Motion System

The purpose of the motion system is to allow the user to change the area of interest that is captured by the video camera. The operator can accomplish this through the provided graphical user interface. From the base station, the instructions will be sent wirelessly to the corresponding servo motor.

5.1 Physical Lay-Out

The motion is provided by two actuators: Servo #1 and Servo #2. Figure 5.1 shows the physical mounting of both servomotors.

Servo #1:	Drives a gear box concentric with the wooden shaft while fixated in an electronic enclosure. This servo dictates azimuth rotation of wooden bracket and camera about X-axis (Figure 5.1). It is capable of 360 degree continuous rotation.
Servo #2:	Is directly fastened onto the wooden bracket and serves to rotate the camera body. This servo dictates vertical dip rotation about Z-axis (Figure 5.1).

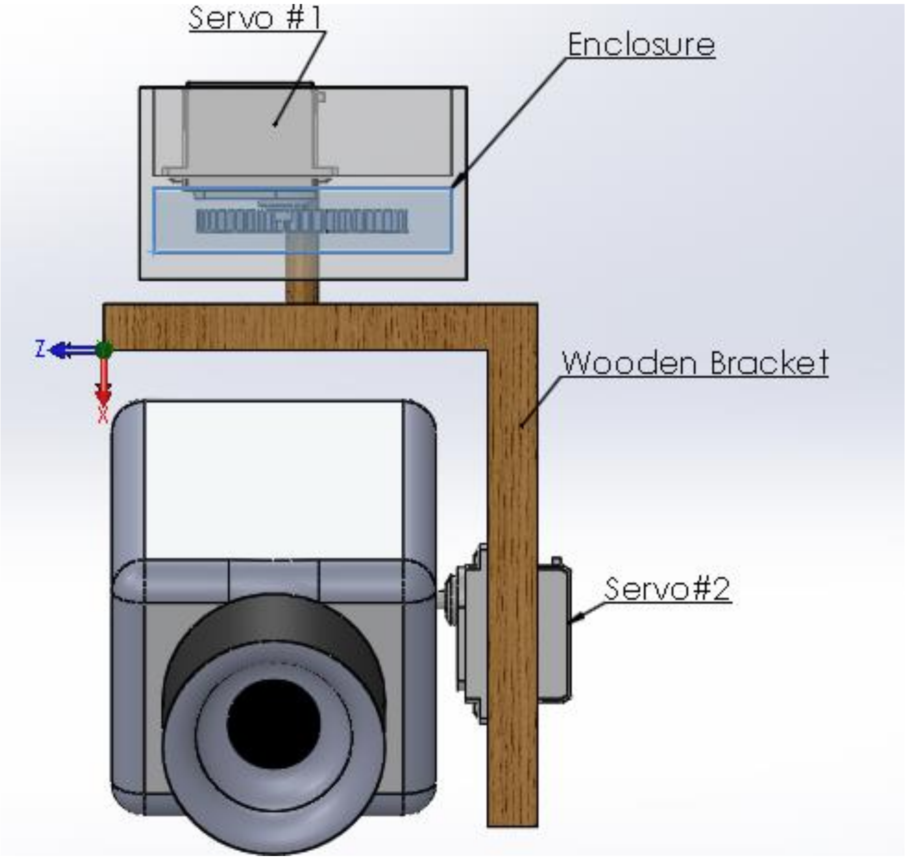
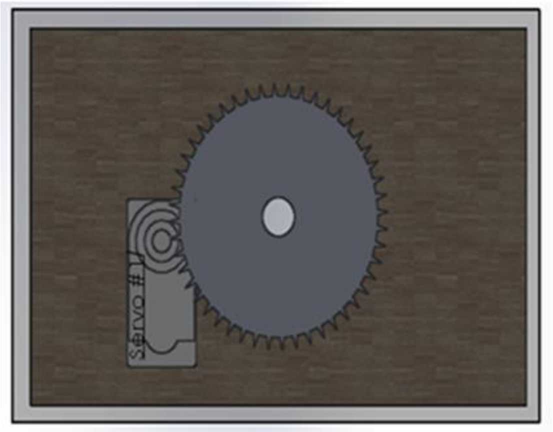


Figure 5.1: 3D rendering of motion system layout

5.2 Mechanics

Servo #1: Figure 5.2a shows the gear mating inside the enclosure. The servo is directly concentric with a 24-teeth gear N1 which has a 1:5 mating ratio with a 120 teeth gear N2 as shown in Figure 5.2b.



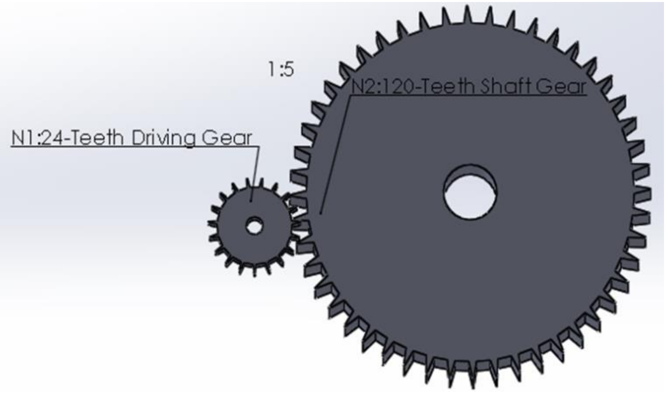


Figure 5.2a: Cross-sectional bottom view of enclosure

Figure 5.2b: Servo #1 Gear ratio

Figure 5.3 demonstrates how the applied toque can be decreased using the two gear

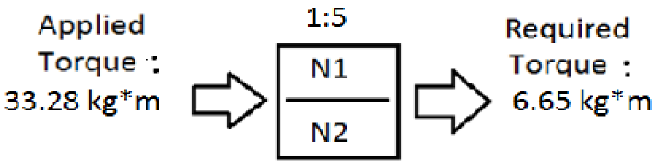


Figure 5.3: Gear ratio effect on torque

Using such gear ratio enhances the azimuth rotational resolution. Implementation of a gear ratio of 1:5 increases resolution by a factor of 5.

$$T_{required} = 6.65\ kg * m$$

Servo #2: Figure 5.4 shows how camera is approximated as perfect cylinder.

Figure 5.4a 3D rendering of camera [13]

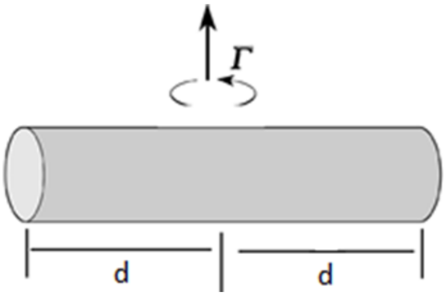


Figure 5.4b: Cylindrical approximation of camera

Assuming servo#2 will be pivoted at midpoint, using the nominal dimensions; the moment of inertia of the camera is calculated using

$$J = \frac{M * d^2}{2} = \frac{0.620kg * 0.0775m^2}{2} = 0.375\ g * m^2 \qquad (5.1)$$

where *d* represents half of camera length and *M* denotes the camera mass [11]. In order to realize the upper bound torque, the mass M is assumed to be localized to the end of the cylinder where d and F are perpendicular vectors turn as conveyed in Figure 5.5.

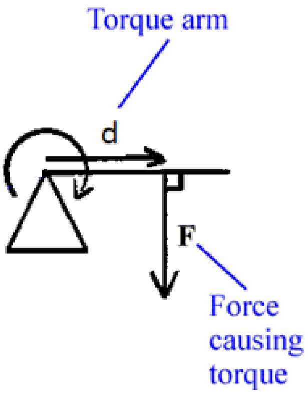


Figure 5.5: Force diagram [5]

The torque required calculated using [11]:

$$\tau = F \times d = \ (0.075\text{m})(0.620\text{kg} * 9.8\text{m}/s^2)\sin 90^\circ \ = \ 0.04557\ \text{kg} * \text{m} \qquad (5.2)$$

Considering Parallax 900-00008 maximum torque capability of: $33.82\ kg * m$ [2], it is evident that, Parallax 900-00008 Servo#2 is 700 times more capable to handle load associated with respective camera. The excess capability is contingency factor to reduce potential physical stress onto servo motor.

5.3 Bracket Design

The wooden bracket is meant to provide a pivot for the camera to attain vertical dip as the motor rotates. Wooden bracket is assembled by linking two wooden planks via a 'Finger Joint' connection. As shown in Figure 5.6 the planks are cut in teeth like pattern to increase the surface area at which they mate. The two planks are cut reciprocal to each other and establish a strong bond with "Carpenter's Glue".

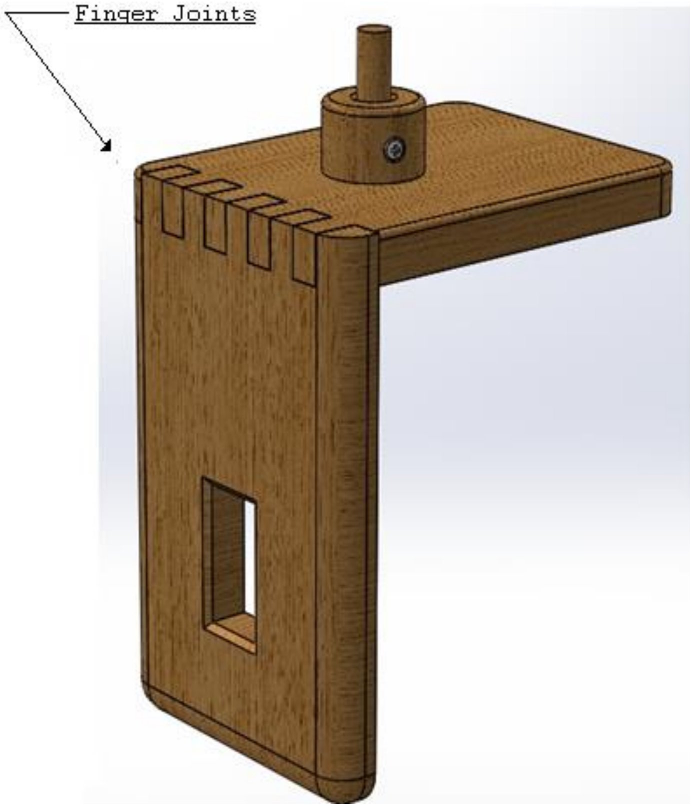


Figure 5.6: Finger joint on wooden bracket

5.4 Controllability

Both servo motors are controlled wirelessly from a base station. As mentioned in wireless network section, the Wi-Fi shield establishes a server-client connection with the base station. Instructions are inputted as arrow keys on client side and transmitted as ASCII characters for the microcontroller to process. As shown in Figure 5.7 the ASCII instructions are the outputted as PWM signals.

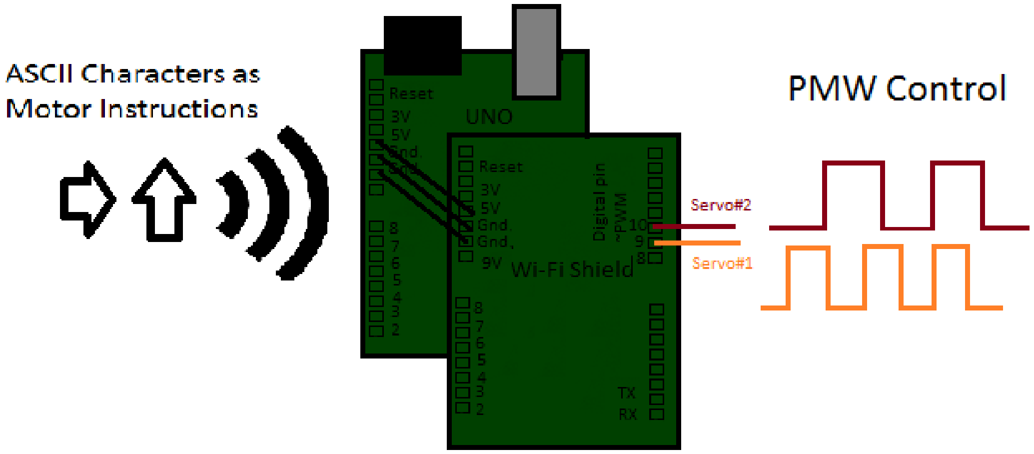


Figure 5.7: Data transmission and processing

The outputted pulses in Figure 5.8 run for 200 us to dictate a resolution of 5^{o} per instruction in the respective direction.

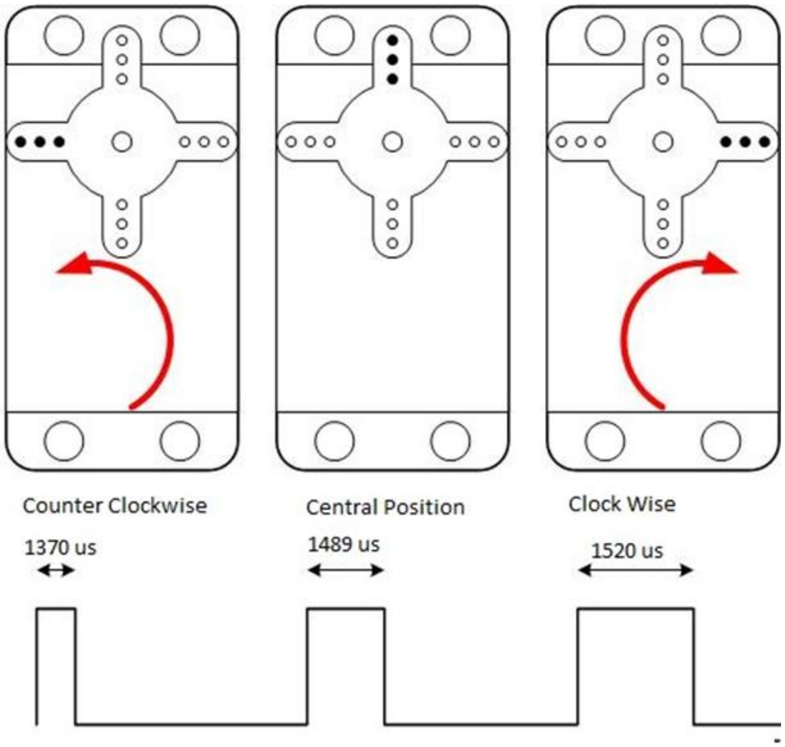


Figure 5.8: Pulse values based on experimental data, adapted from [10]

6 Wireless Network

SkySeed's wireless network serves as the connection between the IP camera, the Wi-Fi shield that controls the camera, and the user interface. As a result, the user receives the video stream as well as necessary system information. With this information, the user has the ability to control the camera orientation, and obtains instant feedback through the video stream.

There are several reasons for which the network was chosen to be a wireless local area network (WLAN). The wireless aspect is to ensure accessibility to the user at any location within a specific range and also to remove the need of Ethernet cables. Using an Ethernet cable to access the video stream would increase the weight of the system which would in turn increase the volume of helium required for proper lift. Wi-Fi supports communication between multiple devices in a network that complies with the 802.11 standard, and is therefore most suitable for the Panalloon network.

The network diagram below outlines how each device communicates with one another over the wireless network. In the centre is the wireless router that creates the Panalloon network and forwards data between the source node and the destination node. The Wi-Fi Shield connects to the network, receives commands from the user, and relays them to the Arduino for processing. When the IP camera connects to the network, the video stream is wirelessly transmitted to the network and can be seen simultaneously by up to four viewers within the network. The base station provides the user interface, allowing the users to view the video stream and control the camera orientation.

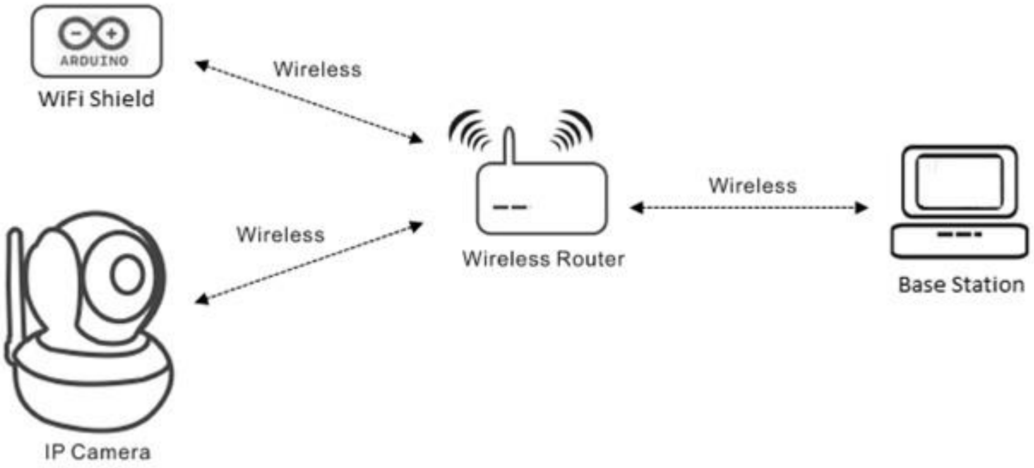


Figure 6.1: Panalloon network diagram, adapted from [16]

6.1 Router

The wireless network will be set up by the router as shown in Figure 6.1. The network devices wirelessly connect to the router, where they are assigned a unique Internet Protocol address (IP address) determined by the network administrator. The router uses these IP addresses to simplify the data routing process.

For the proof-of-concept, the router will be located at the base of the aerial system. For that reason, we chose to use the TRENDnet USB-powered router with specifications described in the Table 6.1 below [15].

Table 6.1: TRENDnet Router Specifications

Wireless Standard	802.11b/g/n
Wireless Speed	300 Mbps
Network Security	▪ WPA, WPA-PSK, WPA2, and WPA2-PSK security standards ▪ WPS button for Wi-Fi WPS configuration ▪ PPPoE/PPTP/L2TP protocol for DSL connections ▪ Firewall protection
Power Consumption	< 2.5 Watts
Size	6.1 x 8.1 x 1.8 cm
Weight	45.36 g

6.2 Wi-Fi Shield

User inputs are received by the Wi-Fi shield for processing. The pin layout of the Wi-Fi shield hardware device allows the shield to be securely stacked on top of the Arduino Uno. Communication between the Arduino Uno and the Wi-Fi shield is controlled by the Serial Peripheral Interface (SPI) bus using digital pins 11, 12, and 13 on the Uno. This shield is based on the HDG104 wireless LAN 802.11b/g system and provides a network IP stack capable of both TCP and UDP [16]. The shield supports both WPA2 Personal and WEP encryption methods.

For the SkySeed proof-of-concept, the Wi-Fi shield connects to the Panalloon network using WPA2 encryption method and is assigned a static IP address of 192.168.0.101. Once connected, the Wi-Fi shield serves as a server that listens for incoming connections from the UI on port 2390. When the client connects to the port, the Wi-Fi shield starts listening for incoming data transmitted over TCP. The received data is then processed in order to move the servo motors.

6.3 IP Camera

The Internet Protocol camera (IP camera) connects to the wireless network using WPA2 personal encryption. Upon network connection, the IP camera is assigned a static IP address of 192.168.0.115. The video stream is uploaded in Common Gateway Interface (CGI) source format to Hypertext Transfer Protocol (HTTP) port 99.

In order to meet the video system requirements [R-55-A] to [R-59-A] and [R-61-A] to [R-64-A], we chose to use the WANSCAM H.264 Waterproof Outdoor IP Camera for SkySeed's proof-of-concept. The specifications for this model are listed in Table 6.2 below [17].

Table 6.2: WANSCAM IP Camera Specifications

Picture Resolution	1280 x 720
Frame Rate	5 – 25 fps
Video Compression format	H.264
Wireless Standard	802.11 b/g/n RJ-45
Network Security	WEP/WPA/WPA2 encryption support
Network Protocol	HTTP FTP TCP/IP UDP SMTP DHCP PPPoE DDNS UPnP
Power Consumption	DC 12 V / 1 Watt
Night Vision	Yes

Waterproof	Yes
Dimensions	15.7 x 8.0 x 7.0 cm
Weight	756 g

6.4 Base Station

The base station serves as the client when connected to the wireless network. The User Interface (UI) enables the base station to communicate with both the Wi-Fi shield and the IP camera using their unique IP addresses. In order to access the video stream, the UI connects to port 99. Next, the UI uses a socket to connect to port 2390, as defined by the server (the Wi-Fi shield in this case.) Whenever valid user commands are detected by the UI, the corresponding data is transmitted over TCP to the Wi-Fi shield. TCP, as opposed to User Datagram Protocol (UDP), is a complex handshaking algorithm that ensures the transmission of all data packets. The use of a TCP based system guarantees that all data packets arrive to the receiver as intended, with a minimal latency cost. More detail on the operation of the UI is provided in the software section.

7 Software

Software is a critical component of SkySeed that controls all its functionality. The UI controls the system and is the main source of feedback to the user. It also allows the user to adjust the speed of the camera motion and empowers the user to record the video stream. The data transmitted from the UI to the Arduino microcontroller uses TCP to ensure all data is sent and received. As discussed in the 'Wireless' section of this document, TCP provides reliability and security to SkySeed. Following data transmission, SkySeed takes advantage of the capabilities of the Arduino Uno(selected for 16MHz clock speed Wi-Fi enhancement).And the Wi-Fi shield to receive data and control the servomotors This section will ensure that the design meets the functional specifications [R-2-A] to [R-5-A], [R-55-A] to [R-59-A], [R-65-A], [R-66-A] and [R-70-A].

7.1 Micro-controller

The preferred microcontroller for SkySeed is the Arduino Uno board along with the Arduino Wi-Fi shield. The flowchart of the microcontroller program is shown in Figure 7.1 and is explained in detail in this section.

Initially the servos are programmatically attached to the Arduino board's specific pins. The pins can be any of the general-purpose input outputs (GPIOs) pins of the board except pin 9, since the Wi-Fi shield uses this pin. After attaching the servos, each servomotor is given a certain pulse width in order to remain stationary. Following initialization, attempts are made to connect to the Panalloon network and start the server. The Wi-Fi shield will act as the server and the UI will be the client. The server will send a confirmation message upon establishing a client connection. If the client does not receive the confirmation message, the program will check for a successful connection and act accordingly. Upon the arrival of the confirmation message to the client, the server will read incoming servo instructions and control them accordingly.

The servos will only move if a valid message is transmitted via the UI. This also means that the lack of instruction arrival will keep the servos stationary. Since the program is written inside a loop, the start of each loop will check the status of the connection. If the connection has dropped, a reconnection will be attempted and the server will once again restart.

It should be noted that packet loss, though minimized by the use of TCP, is a reality in all communication networks. However, because of the nature of the design, as well as the real-time feedback provided by the video stream, packet loss is not a critical issue. In the unlikely case that a directional command is lost, the user will quickly realize that the input was unsuccessful and will send it again by clicking a UI button or pressing a valid key.

The implementation of the Arduino program is available from Panalloon Systems upon request.

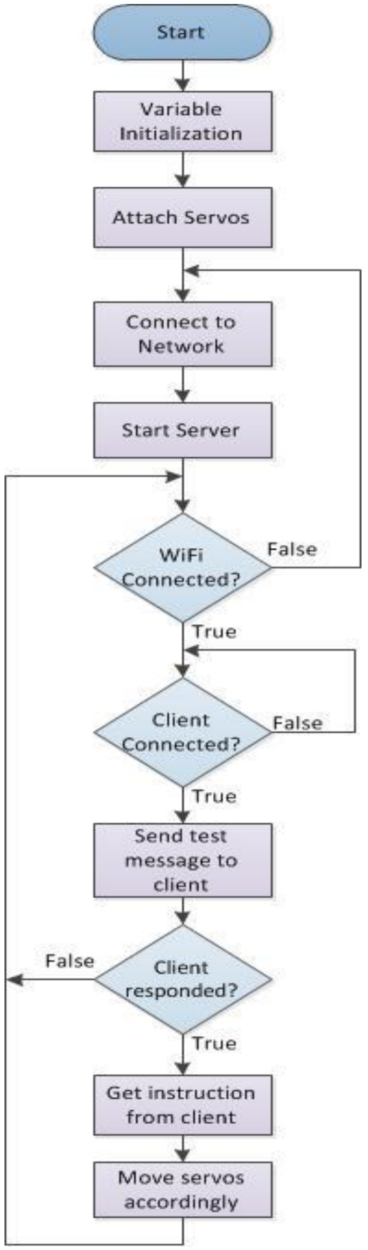


Figure 7.1: Flowchart describing the Arduino program algorithm

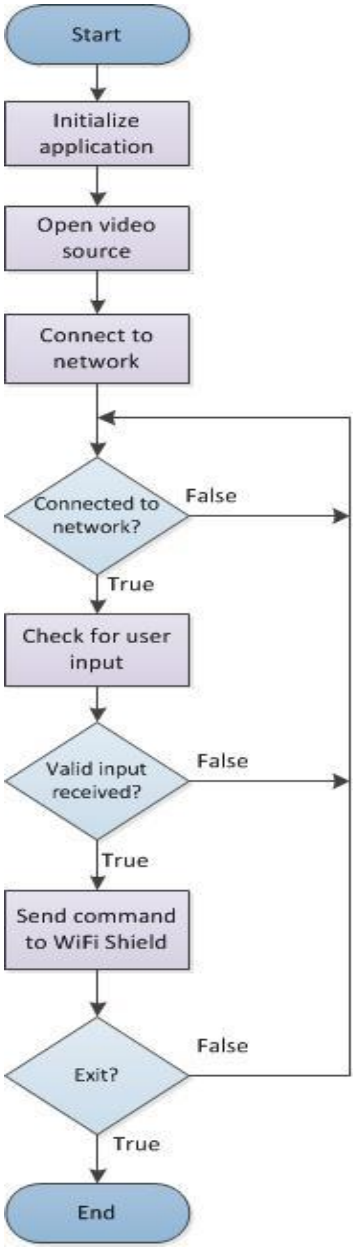


Figure 7.2: Flowchart describing the user interface algorithm

7.2 User Interface

The User Interface (UI) serves as the primary controller of the system and will be installed on a computer that is connected to the Panalloon network. Using this network connection the UI will receive and display the video feed from the camera. Figure 7.3 below is a snapshot of the UI and describes its core functionality.

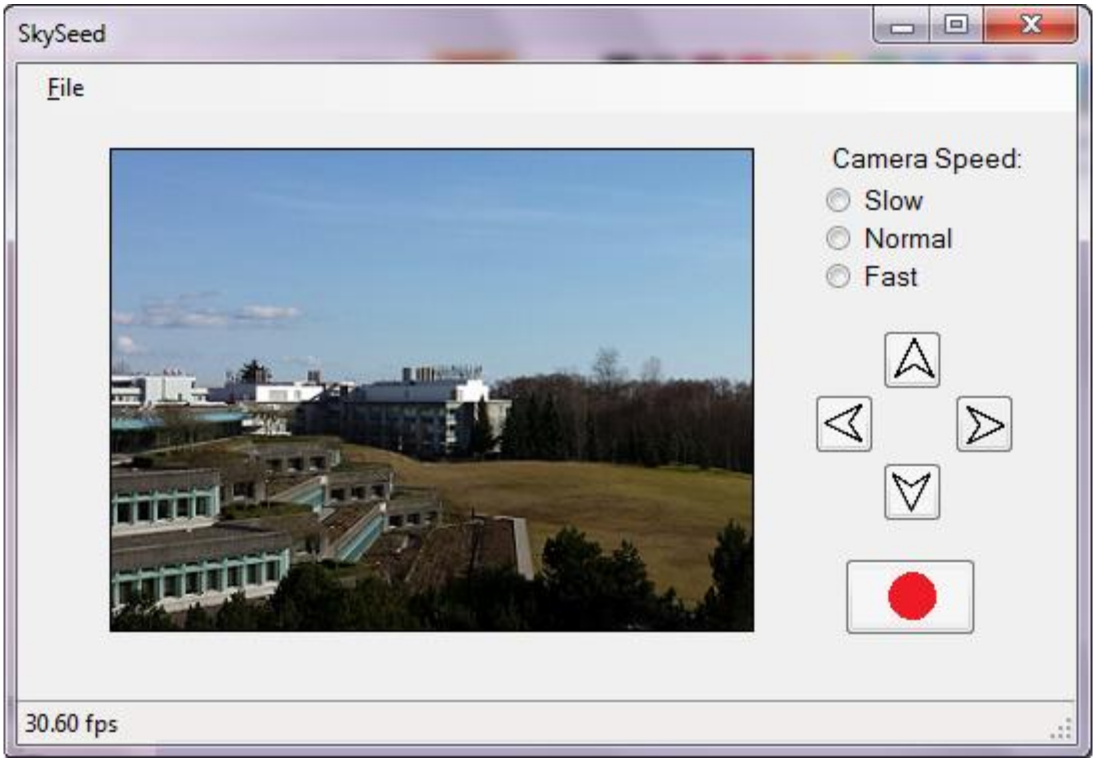


Figure 7.3: Screen capture of the SkySeed user interface

Figure 7.2 describes the UI algorithm. After starting the UI the user will be presented with the video feed and will be automatically connected to the Wi-Fi shield server. If the Wi-Fi shield is not present or a video feed is not attainable, the user will be alerted via system status boxes on the UI (‘status box’ under development). Furthermore, the UI will continuously attempt to connect the server until a connection is established.

Once a successful connection is established the UI will take user input and send each message to the server where it will be processed. The user can control the servos by using buttons on the UI or using the directional keys of the keyboard. Since the user has the ability to hold a keyboard button and send many inputs to the servo, a solution was proposed to predefine the inputs per second. In order to accomplish this task, the system clock was used to ensure that only three inputs per second are sent to the servomotors. The user also has the ability to control the speed of the camera. Three options (slow, normal, and fast) are provided to the user and each option uses a certain pulse width to move the motors. Finally, the UI allows the user to record up to 10 minutes of video stream in case of emergency. The user will be able to set the file location for the stream to be saved. Once the record button is pressed it will continuously record for 10 minutes unless the user stops the recording. Also once 10 minutes has passed the recording feature will automatically stop.

The design of the UI is meant to be simple and provide usability. For that reason, the functionality of the TCP and the synchronous socket is hidden from the user. To establish a connection, TCP uses a three-way handshake between the server and the client. This handshake process verifies the stability of the connection by ensuring that both the client and the server receive acknowledgement of the connection. As a result, the user will be notified that the connection is successful by the use of a status message on the UI. The C# Windows form implementation of the UI algorithm is available upon request.

8 SkySeed Test Plans

Testing procedure/criteria of SkySeed's sub-systems and as an integrated unit integrated. Refer to Appendix B for details on SkySeed's test plan.

8.1 Aerial System Test Plan

The aerial system should provide adequate lift and remain stable enough for the surveillance system to function without any interference. A detailed test plan is devised to test the flight worthiness of the helium balloon, along with its netting system, and the enclosure parachute system.

Appendix B.1: page 24

8.2 Power Test Plan

The power system must provide appropriate voltages and adequate current supply to all of SkySeed's electronics in a safe and reliable manner. To determine whether these feats behave as expected, a rigorous testing scheme is devised to test for safety and performance under varying conditions.

Appendix B.2: page 26

8.3 Motion System Test Plan

The motion system should change the orientation of the video camera in a prompt and smooth manner. These qualities will be verified through a rigorous testing scheme that puts the electro-mechanical system to its limits.

Appendix B.3: page 28

8.4 Wireless Network Test Plan

The wireless network must provide reliable signal strength to all components within the Panalloon network. The tester should ensure that network connection is maintained when SkySeed is at a minimum elevation of 15 m. The video feed should behave consistently at this elevation. As well, the user input should arrive to the WiFi shield without any delay as seen by the user in order to meet requirement [R-2-A].

Appendix B.4: page 30

8.5 Software Test Plan

The user interface should be reliable and display necessary information to the user, without any irrational behavior. The tester has the responsibility to navigate through the UI and ensure that all controls behave as intended. In the process, the tester should attempt to break the software in order to expose any potential bugs or software shortfalls.

Appendix B.5: page 31

8.6 System Integration Test Plan

Each individual system has been tested separately before integration however the process of the System Integration Testing is to ensure that it meets all our functional specifications. All test cases for individual systems will be repeated on the integrated system to ensure correct behavior before performing the System Integrated test cases. The primary goal is to detect defects before User Acceptance Testing.

Appendix B.6: page 33

9 Conclusion

In this document the technical aspects of the aerial, motion, and power systems along with the wireless network and software components were presented in detail and will be utilized in the design of SkySeed. The chosen design path will ensure that SkySeed meets its A -requirements specified in the *Functional Specifications for SkySeed* [1]. Furthermore, test plans were designed in order to determine the reliability and functionality of SkySeed. These test plans include individual and integrated tests to guarantee the overall performance. As of now, the development of the individual components is close to completion; However the integration and testing stages remain to be completed. Panalloon System foresees the completion of the proof-of-concept to be in good time and deliverable by April 1st 2014.

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Appendix A

Reliability

TableA.1 provides justification for primary failure events. The primary events are represented in a circle in the fault tree Figure A.2 and are tabulates from left to right.

Table A.1: Primary Failure Justifications

Primary Failure	**Termination Justification**
Prevention Failure	
Parachute fails to open	Physical obstruction and Entanglement of parachute
Aerial System Failure	
Balloon membrane punctured	Surpassing tolerable helium pressure, contact with invasive material, Strain exceeding Young modulus of Chloroprene Material
Weight Increase	atmospheric rain and snow adding to payload
Netting system is severed	Strain exceeding Young modulus of netting strings
Power System Failure	
Battery running out of energy	Overconsumption, low temperature environment
Wire damaged	contact with invasive material
Communication Failure	
Out of range	Throughput not suffice to establish client-server connection
Video Camera Failure	
Hardware failure	Testing/validation done by manufacturer not valid
Firmware failure	Testing/validation done by manufacturer not valid
Motion System Failure	
Mechanical failure	Gear, wooden bracket, servo, shaft, malfunctioning

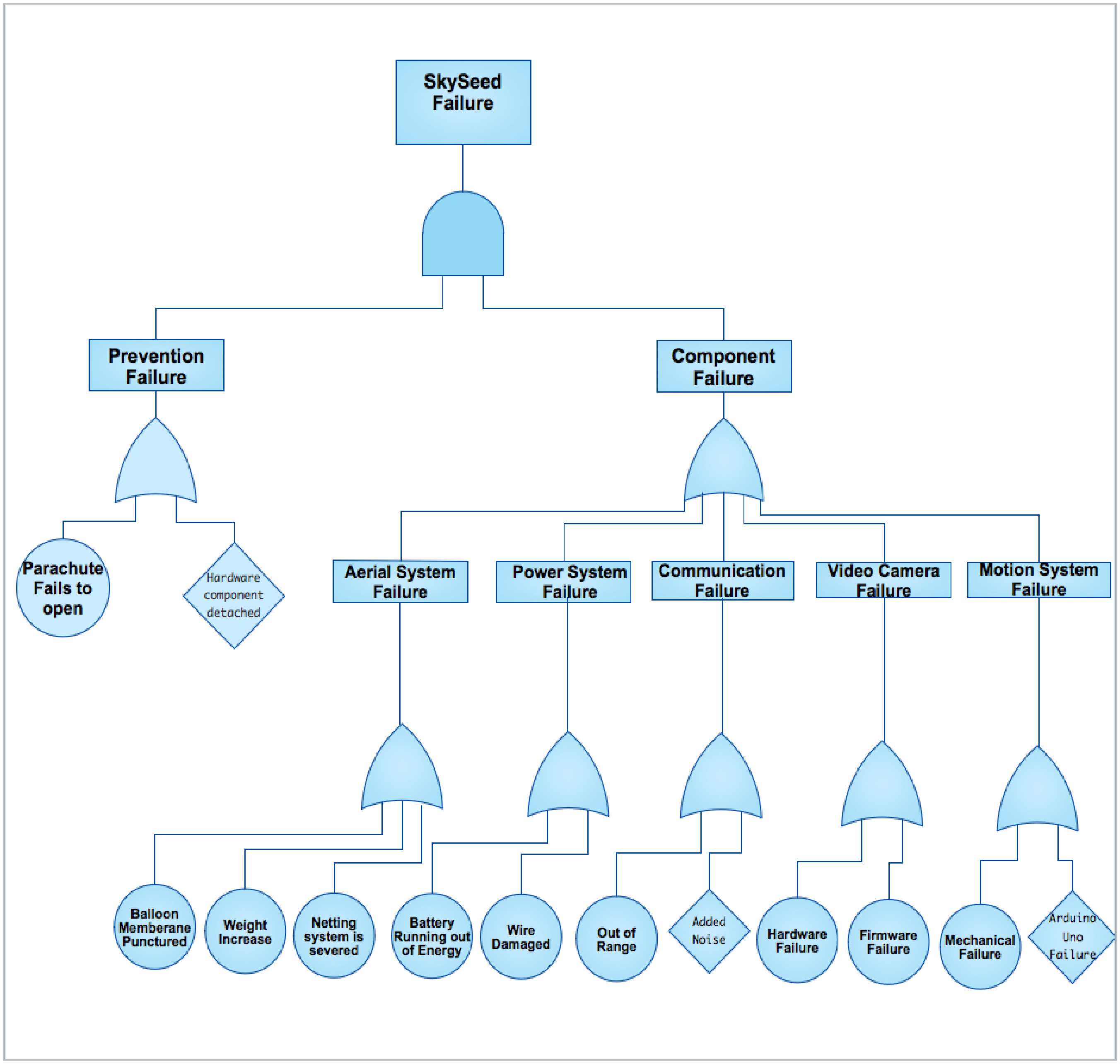

Figure A.1 SkySeed's component failure analysis (Fault Tree)

Appendix B

B.1 Aerial System Test Plan

Purpose

To ensure the aerial system can provide adequate lift, and remain relatively stable to keep user sensible of his/her surroundings. Also, the system's height must be adjustable to a desired height up to a maximum of 30 m.

Test Cases

A. Helium Balloon

1. Attach 1.1kg (recommend lift) at 20 m, 25 m, and 30 m elevations
2. Attach 1.54kg (electronics + enclosure + camera) at 20 m, 25 m, and 30 m elevations
3. Attach 2.2kg (maximum lift) at 20 m, 25 m, and 30 m elevation

B. Netting

1. Entrap balloon hemisphere inside netting
2. Attach 1.54 kg weight on an actuator connected to balloon netting
3. Use video attached to enclosure to interrupted relative stability in 15km/h wind speed

C. Parachute

1. Attach 0.7 kg to parachute and drop at 30 m height

Test Sheet

Aerial System Test	
	Tester Name: **Date:**
Results	**Comments**
Helium Balloon	
A1. successfully lift 1.1 kg to 20 m, 25 m, and 30 m elevation ☐Pass ☐Fail	
A2. successfully lift 1.54 kg to 20 m, 25 m, and 30 m elevation ☐Pass ☐Fail	
A3. successfully lift 2.2 kg to 20 m, 25 m, and 30 m elevation ☐Pass ☐Fail	
Netting	
B1. Netting lays fitted on balloon: ☐Pass ☐Fail	
B2. Torque must not be apparent: ☐Pass ☐Fail	
B3. Visual sensibility from point of interest: ☐Pass ☐Fail	
Parachute	
C1. Parachute has impact velocity less than 1.98m/s: ☐Pass ☐Fail	

B.2 Power System Test Plan

Purpose

The goal of this test plan is to determine if the safety features and performance of the power system (specifically the current limiting mechanism, power switch, and battery life) are up to par with the functional requirements.

Test Procedure

D. Current Limit

A1. Drawing an excessive amount of current over the power circuitry:

- The fuse should go into high impedance mode when the current is above to 1.3 A after 5.0 s approximately
- After a 1 min the fuse should reset

A2. Applying the same test above at different temperatures (10 C and 25 C):

- The fuse should go into high impedance mode when the current is above to 1.3 A after 5.0 s approximately
- After a 1 min the fuse should reset

E. Power Cut-off

B1. When the switch is in the on position:

- The output ports should be outputting approximately 12 V
- The LED light should be ON

B2. When the switch is in the off position:

- The output ports should be outputting approximately 0 V
- The LED light should be OFF

F. Battery Life

C1. Applying a load that draws the same current (1.13 A) as SkySeed’s electronics:

- The battery should last at least 8 hours

C2. Applying the same test above at different temperatures (10 C and 25 C):

- The battery should last at least 8 hours

Test Sheet

Power System Test	
	Tester Name: **Date:**
Results	**Comments**
Current Limit	
Temperature 1:	
A1. Fuse triggers near 1.3 A: ☐Pass ☐Fail	
A1. Fuse triggers near 5.0 s: ☐Pass ☐Fail	
A1. Fuse resets after 1 min: ☐Pass ☐Fail	
Temperature 2:	
A1. Fuse triggers near 1.3 A: ☐Pass ☐Fail	
A1. Fuse triggers near 5.0 s: ☐Pass ☐Fail	
A1. Fuse resets after 1 min: ☐Pass ☐Fail	
Switch Cut-Off	
B1. Voltage is approximately 12 V: ☐Pass ☐Fail	
B1. LED is ON: ☐Pass ☐Fail	
B2. Voltage is approximately 0 V: ☐Pass ☐Fail	
B2. LED is OFF: ☐Pass ☐Fail	
Battery Life	
Temperature 1:	
C1. Battery outputted 12 V for at least 8 h: ☐Pass ☐Fail	
Temperature 2:	
C2. Battery outputted 12 V for at least 8 h: ☐Pass ☐Fail	

B.3 Motion System Test Plan

Purpose

To ensure the motion system behaves smoothly and promptly. Also, the system should continue operating under maximum and average load without drawing excessive current.
Note: Test cases are valid with external power supply (Not from Microcontroller)

Test Procedure

A. Servo Testing

A1. Ensure that the servo is able to move

- Servo should move when 5V is supplied

A2. Measuring different current draw based on the load

- Under 5 V applied voltage read current drawn with No Load,
- Under 5 V applied voltage read current drawn with 0.116 Nm Load
- Under 5 V applied voltage read current drawn with 0.31 Nm Load (Maximum Load)

A3. Apply different pulse width to observe rotations in both directions.

- Motor must remain neutral (no rotation) under 1489 μs pulse width
- Motor rotates clockwise with 1700 μs pulse
- Motor rotates counter-clockwise with 1300 μs pulse

B. Microcontroller + Wi-Fi Shield

B1. Making sure the expected movement can be achieved with a wireless connection.

- Servo must behaves in a smooth manner and without visible delay
- Servo must draw less current than 300 mA

C. Gear Box Testing

C1. Tester ensuring that the correct revolution is observed with different pulse width

- Output gear must not exceed 5^0 revolution under 1520 μs pulse width
- Output gear revolution increase when pulse width is 1700 μs

D. Wooden Bracket Testing

D1. Apply 0.75 g of downward load for period of 8 hours to ensure durability of the material.

- Wooden bracket must not show any sign of dislodgment
- Wooden bracket must not show any sign of material sheering

Test Sheet

Motion System Test	
	Tester Name: **Date:**
Results	**Comments**
Servo Motor Testing	
A1. Motor must remain responsive with 5 V supplied: ☐Pass ☐Fail	
A2. Motor must not exceed 1 A of current draw ☐Pass ☐Fail	
A2. Motor draws less than 500 mA under 0.116 Nm of load: ☐Pass ☐Fail	
A2. Motor draws less than 100 mA under No load: ☐Pass ☐Fail	
A3. Motor must remain neutral (no rotation) under 1489 μs pulse width: ☐Pass ☐Fail	
A3. Motor rotates clockwise with 1700 μs pulse: ☐Pass ☐Fail	
A3. Motor rotates counter-clockwise with 1300 μs pulse: ☐Pass ☐Fail	
Microcontroller + Wi-Fi Shield Testing	
B1. Servo has no visible delay: ☐Pass ☐Fail	
B1. Servo must draw less current than 300 mA: ☐Pass ☐Fail	
Gear Box Testing	
C1. Output gear must not exceed 5^0 revolution: ☐Pass ☐Fail	
C1. Output gear revolution increases ☐Pass ☐Fail	
Bracket Testing	
D1. Wooden bracket must not show any sign of dislodgment: ☐Pass ☐Fail	
D2. Wooden bracket must not show any sign of material sheering: ☐Pass ☐Fail	

B.4 Wireless Test Plan

Purpose

The purpose is to test the signal strength and network reliability, and to provide a consistent video stream at 15 meter elevation. As well, these tests should demonstrate that commands are received and processed by the Wi-Fi shield in time delay unnoticeable by the user.

Test Procedure

A. Signal Strength

A1. Reliability
- Network should not fail unless power source is removed
- Network signal strength remains consistent within 20 m elevation
- Minimum wireless speed of at least 150 Mbps

A2. Video stream
- Video stream displays minimal latency

B. Command Time

B1. Use the directional buttons to test for real-time response
- All directional inputs result in real-time camera motion

Test Sheet

Wireless Network Test	
	Tester Name: **Date:**
Results	**Comments**
Signal Strength	
A1. Network stable: ☐Pass ☐Fail	
A1. Network stable within 15 m: ☐Pass ☐Fail	
A1. Wireless speed of 150 Mbps within 15 m: ☐Pass ☐Fail	
A2. Smooth video stream: ☐Pass ☐Fail	
Command Time	
B1. Real-time motion: ☐Pass ☐Fail	

B.5 Software Test Plan

Purpose

The purpose is to test the reliability of the UI and ensure its usability under any user input. Furthermore, the following will also test the functionality of the microcontroller program with the use of the user interface.

Test Procedure

A. UI Testing

A1. Attempt to break the UI by supplying random inputs at any time. Tester should make sure of the following:

- UI should remain responsive at all times
- UI reacts in a timely and predictable way to unpredictable user inputs

A2. Disconnect the UI from the Panalloon network to ensure that the user is notified through UI status updates. The following should be observed:

- "Network disconnected. Trying to reconnect.." message display on UI
- User should be unable to click directional buttons
- A "Connection time out" status should be shown in the video source player

A3. Test video record functionality. Attempt to record a 15-minute video, in order to test the recording limit

- If video file location not specified, file default location is set
- Saved video file can be opened and viewed once recording is stopped
- UI should terminate the video recording after 10-minutes of recording
- User should be notified of recording termination
- If user exits program during recording, video recording is terminated

B. Microcontroller testing

B1. Disconnect the microcontroller from the network and observe:

- User should be unable to click directional buttons
- Status updated to notify user that UI is disconnected from server

B2. Use the directional buttons to test for appropriate, non-delayed motion

- All directional inputs result in appropriate camera motion, as verified by video feed
- Holding down a directional key results in a maximum of 3 inputs/sec

B3. Speed selection controls camera motion accordingly

- Three speed options result in varying speed of camera

Test Sheet

Software Test	
	Tester Name: **Date:**
Results	**Comments**
UI Testing	
A1. Remains responsive: ☐Pass ☐Fail	
A1. Predictable behavior at all times: ☐Pass ☐Fail	
A2. Appropriate status message: ☐Pass ☐Fail	
A2. User unable to click direction buttons: ☐Pass ☐Fail	
A2. “Connection time out” status shown in video box: ☐Pass ☐Fail	
A3. Video file saved in default location: ☐Pass ☐Fail	
A3. Recorded video file can be opened and viewed: ☐Pass ☐Fail	
A3. Video record terminated at 10 minutes: ☐Pass ☐Fail	
A3. User notified when recording terminates: ☐Pass ☐Fail	
A3. Video saved when user exits program: ☐Pass ☐Fail	
Microcontroller Testing	
B1. User input buttons disabled: ☐Pass ☐Fail	
B1. Status updated to disconnected: ☐Pass ☐Fail	
B2. Directional motion as expected: ☐Pass ☐Fail	
B2. Camera motion halts when key not pressed: ☐Pass ☐Fail	
B3. User speed selection control camera motion: ☐Pass ☐Fail	

B.6 System Integration Testing

Purpose

The purpose is to test the reliability of SkySeed as an integrated system. To ensure that the users are able to control the balloon from the base station while capturing and streaming video from their area of interest.

Test Procedure

A. SkySeed's at a desired elevation

A.1.Elevate SkySeed to desired position, ensure desired behavior

- Ensure camera motion does not cause tether and netting entanglement
- Video feed is received by UI when SkySeed is at elevation.
- System doesn't sway more than 50 m^2 in visibility
- Able to cover a landscape area up to 0.16 km^2 from a 20 m elevation through the UI.

B. Power Testing

B.1. Ensure power is transmitted from base station to electronic enclosure:

- Charged battery can power the entire system for 8 hours.
- Ensure power wire is not sheered with applied human tension.

Test Sheet

System Integration Testing	
	Tester Name: **Date:**
Results	**Comments**
Desired Elevation Testing	
A.1. No entanglement of tether and netting ☐Pass ☐Fail	
A.1. Video feed is displayed on UI ☐Pass ☐Fail	
A.1. Sway of 50 m^2 does not occur ☐Pass ☐Fail	
A.1 0.16km^2 from a 20 m elevation: ☐Pass ☐Fail	
Power Testing	
B1. Power wire stays intact: ☐Pass ☐Fail	
B1. Battery lasts up to 8 hours: ☐Pass ☐Fail	