EE2 Project Group 06

Aerial Surveillance to Tackle Poaching

The Skyno Project

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1. Introduction

Today, poaching of rhinoceros (rhinos) has escalated to critical levels in South Africa. The situation is so dire that the remaining 2 species of rhinos—northern white and eastern black rhinos—are listed on the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species. With some species such as the Africa's western black rhino officially extinct, the need for effective measures to curb poaching is ever so prevalent to ensure the survival of the remaining species [1].

Poaching has numerous and widespread effects. It not only affects the animals directly but also has several negative implications on the society. This is mainly because poaching is funded and carried out by crime syndicates and terrorist groups [2]. The detrimental effects on society and the animal species will be covered further in the report. This austere situation has encouraged organisations from around the world to focus on dealing with this problem.

Most current measures implemented to tackle poaching cause harm to the animals concerned or to the user himself. One such measure is the poisoning of animal horns while yet another involves high risk activities such as infiltrating poacher organisations. However, despite these various methods, poaching still continues to rise exponentially. Therefore, there is a pressing need for an effective solution which can snub this rising trend. Hence, in order to tackle poaching at its roots, Skyno, an aerial surveillance system is implemented.

Skyno aims to integrate aerial surveillance with effective video processing to solve this problem. Research has shown that most poaching activities occur at night [3]. Coupled with the help of thermal imagery, Skyno allows users to effectively monitor hot spots for poaching activities in low light conditions, enhancing the ranger's vision at night. Intelligent video processing algorithms are performed on the video feed obtained to search for potential threats. If identified, the unit alerts the user of potential poaching activities via a software client. Skyno can therefore be considered as an early warning system where users are able to identify threats before the rhinos are harmed. All of this is achieved with a fully automated system with minimal input from the user, making Skyno an easy to implement and cost-effective solution.

The potential for Skyno is immense, from cost savings to network capabilities. It can extend beyond just monitoring at night to 24 hour surveillance of critical areas. Furthermore, various Skyno units can be interconnected to effectively monitor large areas. Plans are underway for the implementation and rigorous testing of the design with Selex ES, a global leader in electronics and information technologies. With the expertise and funding provided by Selex ES, testing and enhancements were made to establish a robust design as will be discussed later in the report.

This report aims to present the research procured by the team on the feasibility of tackling rhino poaching. It also details the proposed device and considerations taken during the design phase. Finally, the report explores potential developments of Skyno and concludes with a cost analysis against other measures currently implemented.

2. Problem Outline

Poaching is defined as the illegal hunting or catching of game or fish on land that is not one's own or in contravention of official protection.

Poaching of rhinos can be traced back to early 20th century (Appendix A) when there was an approximate population of 500,000 rhinos worldwide, dispersed throughout Africa and Asia. Yet, despite intensive efforts in conservation and the implementation of new laws and regulations, the poaching of rhinos has escalated exponentially over the years as illustrated by the statistics in Figure 1. In 2011, the western black rhino was officially declared extinct by the International Union of Conservation of Nature (IUCN).

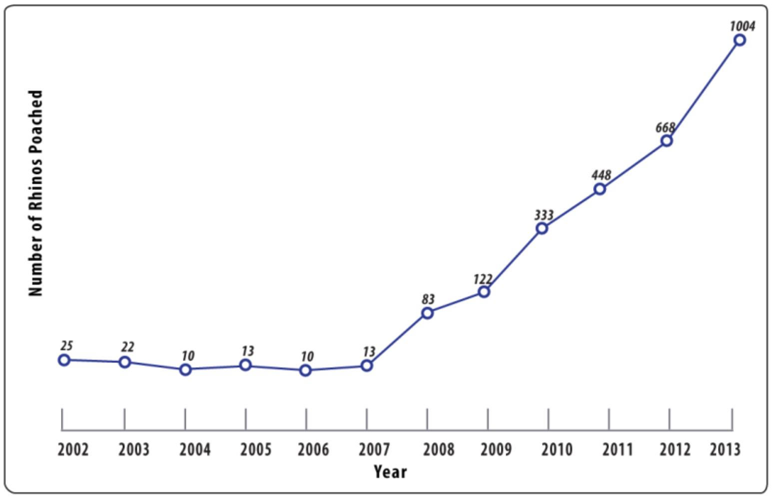

Figure 1 - Number of poaching cases in South Africa by the South African Department of Environmental Affairs [4]

Focus will be placed on South Africa as it is home to 83% of Africa's rhinos and an estimated 73% of all wild rhinos worldwide [4]. In 2013, there were a staggering 1004 rhinos poached in South Africa alone which approximates to almost 3 rhinos killed a day.

Of the eight remaining subspecies of rhinos, there are four in South Africa which are classified as critically endangered on the IUCN Red list [5]. It is estimated that given the current trend in the poaching of rhinos, they are likely to go extinct in the near future [4].

Since one of the main habitats left for these existing rhinos is Kruger National Park, most of the current conservation efforts are focused there. However, from a statistical point of view, despite efforts in conservation, the situation is bleak as poaching has continued to increase exponentially (Appendix A).

Statistics released by the South African Department of Environmental Affairs, show a steady increase in the number of arrests related to rhino poaching. However, with the increase in poaching cases, the number of poached rhinos still far outweighs the arrests made.

Year	Number of poaching related arrests	Number of poaching cases	Arrest percentage/%
2010	165	333	49.55
2011	232	448	51.78
2012	267	668	39.97
2013	343	1004	34.16

Table 1 - Poaching related arrest rates [1] [4]

2.1 Effects of poaching

Rhino poaching not only has a direct impact on the animals themselves but also has social, economic and political effects and causes transmission and spread of zoonotic diseases [6].

2.1.1 Ecosystem

Rhinos are an indigenous population to South Africa and any sharp decrease in its population will cause great instability to the delicate ecosystem of the region. Furthermore, plants rely on animals for both pollination and seed dispersal. The removal of herbivores from an ecosystem alters seed dispersal and seed predation patterns which may lead to defaunation in the ecosystem [7].

2.1.2 Social

Poaching and violence go hand in hand. With most poachers carrying weapons to hunt and kill rhinos, there are bound to be clashes between them and anti-poaching rangers. This is supported by a statement from *Save the Rhino* with regards to poachers who were shot dead [8]. Unnecessary loss of life due to poaching evidently has an adverse effect on the social situation of the region as violence due to armed groups is increased and innocent people may get caught in the crossfire.

2.1.3 Economic

Eco-tourism, which contributes a significant 7% to the economy of South Africa, is badly affected by poaching [9]. The fear of venturing into areas with armed poaching and the bad publicity gained from the poaching of rhinos reduces the number of tourists visiting the region. In a report conducted by the Wildlife and Environment Society of South Africa (WESSA), they concluded that, "the current poaching tide will start to threaten tourism in South Africa unless brought under control" [10]. This, in turn, will decrease the need for jobs such as safari guiding which reduces employment opportunities.

2.1.4 Political

Research conducted by the United States International Conservation Caucus Foundation (USICCF) has found that the terrorist group Al-Shabaab engages in rhino poaching activities to fund its terrorist plots and arms stashing [2]. The problem is seen to be so severe that President Barack Obama has set aside a sum of 10 million USD to help park rangers in a bid to help tackle 10 billion USD worth of wildlife trafficking [11].

2.2 Current Measures

In order to explore the feasibility of Skyno in tackling poaching, there is a need to explore the existing methods that are currently in place with a focus on their effectiveness and costs.

2.2.1 Informants

Overview: This method involves approaching and planting people who can act as informants. This provides conservation trusts with information that leads to the tracking of poachers and thus their arrest.

Limitation: Tackling poaching this way is not reliable as it would require informants to be planted in all crime syndicates around the region to consistently update rangers of poachers' current activities in the wildlife area. Moreover, planting informants may be dangerous for the spy himself because, if caught, they may be injured or killed by the criminals.

Cost: There is no set income given to poaching informants. However, informants are usually rewarded highly if successful in providing sufficient information that leads to an arrest. An example of this is in 1984 when a spy was awarded with $5000 for helping to convict a grizzly bear poacher in the USA [12].

2.2.2 Dehorning of Rhinos

Overview: This method involves tracking rhinos and dehorning them. This removes the profit and thus the motivation behind poaching.

Limitation: Poachers may still kill dehorned rhinos. Dehorning would need to be repeated every cycle after the horn of the animal has grown and as recorded by *Save the Rhino*, even a one off dehorning is expensive.

Cost: US$620 (Kruger National Park) per animal to US$1,000 (private land) to dehorn. It is estimated that it would cost around US$5.8-8.8 million for a one-off dehorning of all the rhinos in Kruger National Park [13].

2.2.3 Poisoning of horns

Overview: This method involves injecting lethal poison such as strychnine, cyanide and anthrax into the horns, harming consumers who consume the horns, thereby reducing demand for these horns. With reduced demand, it reduces the incentive behind rhino poaching. The intent is similar to that of dehorning but does not require a repeated cycle and is only done once.

Limitation: This method poses ethical issues since there is intent to harm or kill others. Cathy, Dean Director of Save the Rhino International, stated regarding this method, that "poisoning rhino horns, with the stated desire of killing or injuring anyone subsequently ingesting it, must be regarded as attempted murder." [14]

Cost: US$800 per horn. It is estimated that it would cost around US$5.6 million for poisoning 7000 rhino horns in Kruger National Park [15].

3. Current Solution

3.1 System Design Objectives

The primary aim of the entire system is to help rangers identify potential poachers entering Kruger National Park on vehicles at night. Additionally, the product must also be able to alert the user if such a threat is identified. The solution comprises of 2 main modules, namely, the hardware and software modules. The specific aspects of the design are listed below.

- Hardware module - The hardware module is responsible for the provision and transmission of reliable and sustainable video feed. It consists of the following components:
  - Power supply - The power supply to the final design must be able to provide stable power for operation of camera and transmitter for at least 12 hours.
  - Camera - The camera chosen must be able to capture video footage under very low light conditions.
  - Transmission – The end design must be able to transfer what is seen by the camera to a computer to carry out the video processing.
- Software module – The software module is the processing unit. It must fulfil the following functions:
  - Video processing – The module must be able to implement intelligent algorithms to identify vehicular movements of poachers from the obtained imagery.
  - Alert system - If a potential threat is found, the end design must be able to alert the user.

3.2 Modular Overview of System

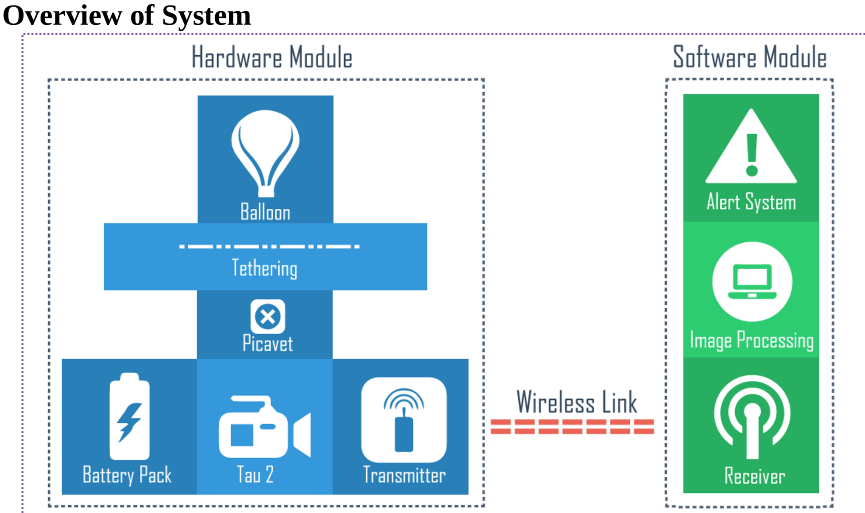

Figure 2 - System diagram showing the modules within

Based on the above specifications, the final design comprises of 2 main modules:

1. The hardware module consists of the physical elements of the design—camera, balloon rig, power supply and transmitters. This module helps to obtain the video feed of area being covered.
2. The software module performs the processing on the video feed obtained from the hardware module to identify threats and alert the user.

Communication between the 2 modules is the most critical part of the design. This will be achieved using a transceiver. The camera will be connected to a 5.8GHz transmitter which has a cloverleaf antenna to increase gain and thus the distance of transmission.

The software module upon receiving the video feed will perform video processing to identify moving vehicles. This is done via a background subtraction technique using Gaussian mixture model. A Java client (Appendix G) is used to receive information through User Datagram Protocol (UDP) connections to the Skyno units. The client allows the surveillance system to alert the users of any possible poaching activities. The user can then refer to the video feed and decide on the appropriate action to be taken.

3.3 Design Configuration Options

3.3.1 Video Processing

Background subtraction using Gaussian mixture model is chosen to implement video object detection [16]. The algorithm constantly learns to identify the static background based on pixel intensity changes [17]. This technique of object detection has an advantage over feature-based object recognition as it does not require a database of car-shaped templates to perform matching.

To assess the effectiveness of the video processing algorithm, a test program written in MATLAB performs this algorithm on video feeds. The MATLAB script and in-depth explanation of the video processing elements can be found in Appendix F.

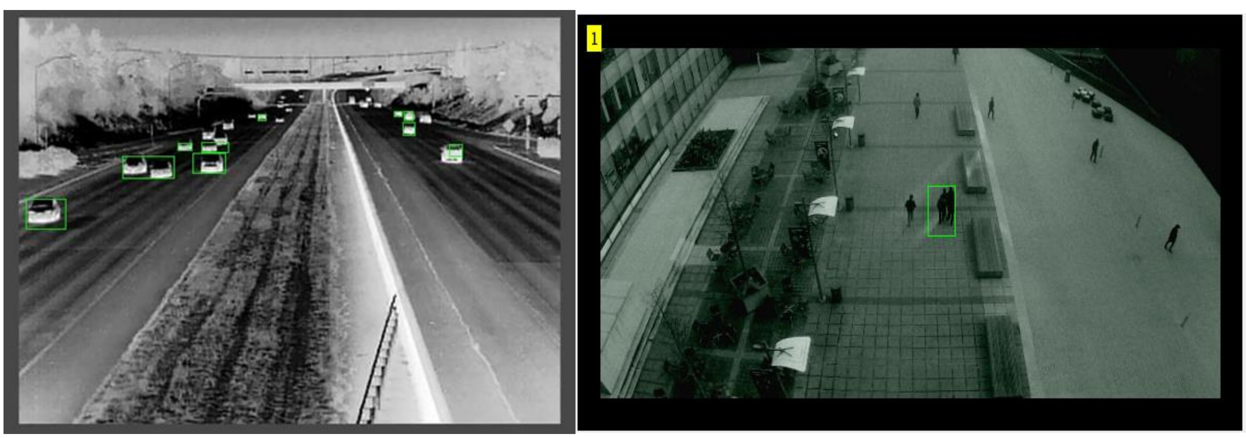

Figure 3 - Video processing results on two separate video feeds

The first test video is a publicly available video observing night time traffic with an infrared traffic camera. As seen from the video frame on the left of Figure 3, moving cars are highlighted by green boxes while cars further back in the scene are too small to be detected. This issue would be avoided in the actual implementation, where a top-down view from the balloon will eliminate the dimension of depth causing poachers' vehicles to stand out as similar sized moving objects.

A field trial was conducted using video feed taken by a GoPro® Hero3+ camera with an applied infrared filter. The result of the video processing shown in the right of Figure 3 illustrates the reliable detection of a larger sized moving object (vehicle) among smaller sized moving objects (animals or humans).

Therefore it can be concluded that with the right imagery, the video processing algorithm can detect poaching vehicles. In order to ensure the reliability of the motion detection, the minimum size of the moving object is limited to 5-by-5 pixels.

3.3.2 Camera

Skyno aims to maximise the area monitored, which is achieved by flying the balloon at the highest possible altitude with a lens that provides the largest Field Of View (FOV) possible. However, flying the balloon at a higher altitude introduces a trade-off in pixel resolution. Pixel resolution, the number of pixels which the target object occupies, reduces with higher altitudes.

The camera must be able to satisfy 2 conditions:

1. Effectively monitor a grid of 50-by-50 meters.
2. Satisfy the pixel resolution of the target object of 5-by-5 pixels.

This grid provides a reasonable reason for the balloon to be deployed at night as rangers will find it difficult to monitor such a large area with their naked eyes. Using these constraints, graphs were plotted to determine the type of camera, lens and altitude the balloon is flown at.

The graph, Figure 4, was plotted to determine the maximum altitude at which the balloon can be flown to satisfy both conditions with varying resolutions and various FOV lens. Since Skyno is deployed at night, a thermal camera is required to effectively monitor the area. The Tau 2 camera was chosen. Thermal cameras have low resolution and hence our focus is on the 128p line in Figure 4.

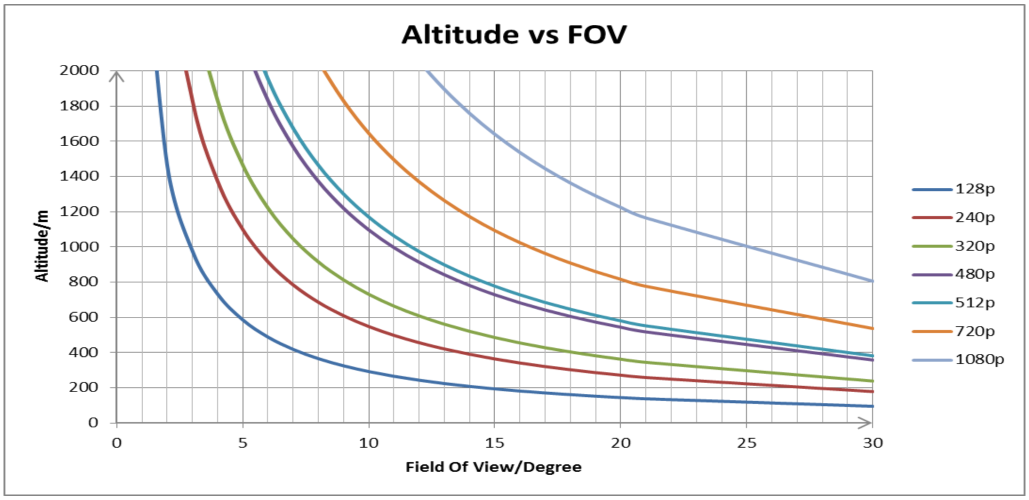

Figure 4 - Graph showing maximum altitude against FOV for different camera resolutions

In order to determine the type of lens, another graph was plotted. The minimum height at which the balloon needs to be flown is determined at various FOVs by fixing the resolution at 128p. This graph can be found in Appendix H. From both graphs, it can be seen that a lower FOV will allow a higher maximum altitude.

Since the Tau 2 has a 7.5 mm lens which has a FOV of 30 by 24 degrees, the worst case of 24 degrees is used to determine the minimum and maximum altitude at which the balloon should be flown. In this case, it has a minimum of 117.6m and a maximum altitude of 119.4m. At this range, the required conditions are satisfied while the tethering wires are not too long to handle. This makes it ideal for the balloon to be flown within the range. Detailed analysis of how these calculations are done can be found in Appendix H.

3.3.3 Transmission

The most critical aspect of the design is the wireless link between the 2 modules. The link is achieved with the help of the 5.8GHz transmitter. Wireless communication was chosen over wired means and 5.8GHz was chosen over 2.4GHz. The detailed explanation on the reasons behind these choices can be found in Appendix D.

Testing was carried out to determine the range of the transmitter by attaching it to a GoPro® Hero3+ and recording the video as part of the demonstrator. Initial results with the default antennas proved unsatisfactory with the range only extending to about 20m. Therefore, cloverleaf antennas were used to improve the range of the system. The cloverleaf antennas are located on the side of the payload, pointing sideways. This is because testing showed that the antennas have a donut shaped radiation pattern. Therefore any region directly above and below the antennas will have weak reception. Analysis of how to extend the range of the transmitter is also described in detail in Appendix D.

With these new antennas, the range of the transmitter extends to about 150m, which falls within the ideal height range of operation discussed in *3.3.2*. The quality of the video obtained is also improved with these antennas. Therefore, it is concluded that transmission between the 2 modules is possible through the wireless link setup.

3.3.4 Power

There are 2 devices which need to be powered on the payload, namely, the FPV 5.8GHz TX/RX 200mw Combo transmitter and the Tau 2 LWIR Thermal Imaging Camera. The calculations below show the total power required by these devices for effective performance. The operation time of the equipment is taken to be 12 hours.

$$P_{Tau\ 2} = 1Wh\ \times 12 = 12Wh$$

$$P_{Transmitter} = 12V\ \times 100mAh\ \times 12 = 14.4Wh$$

$$P_{TOTAL} = 12Wh\ +\ 14.4Wh\ = 26.4Wh$$

One of the primary considerations is the required input voltage for the transmitter. The transmitter requires an input voltage of about 12V while the camera has an input voltage range of 2-6V. In line with the requirements, the transmitter will be powered directly with a Tracer Lithium polymer battery which has an output voltage of 12V. Since the transmitter has the ability to provide a stable output of 5V, it will in turn be used to power the camera. Being light and efficient, this is the ideal power solution for Skyno. The detailed comparison and selection criteria can be found in Appendix B.

3.3.5 Miscellaneous

In order to generate sufficient lift, the weather balloon is filled with pure Helium (He). Details of the volume of Helium required and balloon specifications can be found in Appendix E. The weather balloon is held in place with 4 tethering strings made from Kevlar® lines. The detailed diagram depicting this can be found in Appendix I. In the event where the weather balloon is to rupture, the payload will be kept safe from damage and impact. This is achieved with the help of a parachute attached to the payload as well as encapsulating the whole payload within a PVC pipe padded with sponges within. The PVC pipe helps to reduce the impact on the camera when the payload hits the ground and also helps to weather-proof the entire payload. The detailed calculations for the force of impact and velocity of the PVC pipe are shown in Appendix J.

Another point of consideration is image stabilisation. In order for the video processing algorithm to work effectively, the camera has to be held stationary. Hence to minimise the movement of the camera, both mechanical and software stabilisation are implemented. Mechanical stabilisation is achieved with the help of a Picavet as shown in Appendix C.

4. Potential Improvements/ Higher Functions

4.1 Balloon Network

Weather balloons can be deployed in tandem to each other at spaced out locations, forming an intricate network of balloons. This enables users to monitor vast areas without being physically present. The overlapping of the surveyed area of each individual balloon at different locations allows tri-location to be implemented to accurately pinpoint the exact coordinates of the suspected poaching activity. The rangers would save time and effort, allowing them to take swift and decisive actions against these poachers.

4.2 Smart Frame Rate Throttling

Running the video camera at full frame rate generates redundant information when there is no poaching activity present. By setting the idle frame rate of the camera to a low value—1 frame per second—and then throttling it up to full frame rate video capturing upon detection of movement in the area, the system will be more efficient at information capturing. Slower average frame rates will also consume less energy and video processing power.

5. Conclusion

One of the most significant factors which determine the feasibility of the project is the overall costs incurred. The total costs of implementation of a single Skyno unit costs £1924.77. The detailed breakdown of these costs can be found in Appendix K. At first look, the cost incurred may seem considerably high. However the price of Skyno needs to be put in context and compared with the current measures in place. Table 2 depicts this comparison.

Method	Informants	Dehorning	Poisoning	Skyno
Costs Incurred (USD)	Unquantifiable	~ 5.8 – 8.8 million	~ 5.6 million	~ 3000

Table 2 - Comparison of costs between current counter poaching measures and Skyno

As seen, Skyno is clearly more cost-effective as compared to the current measures discussed here. Furthermore, there is minimal maintenance costs associated with Skyno. Maintenance primarily involves refilling up the balloon with Helium and recharging the batteries.

The primary feature of Skyno which distinguishes it from the rest is the fact that Skyno enables its users to identify threats before any harm is imposed on the animals. Rhino numbers are at such critical levels that methods of curbing poaching which do not result in the direct harm of these animals is imperative for their survival.

Secondly, Skyno requires minimal training to implement. Designed to be straightforward and clear, it is mostly automated, requiring users only to set up the balloon. When a threat is identified, the location can be easily identified with the help of the alert system. Overall, Skyno fits seamlessly into current practices, allowing users to adopt it with minimal training or expertise.

In conclusion, in the long run, the benefits derived from the implementation of Skyno far outweigh the costs associated with it. Skyno is a cost-effective and easy to implement solution. Skyno is a huge step forward to the conservation and protection of these endangered species. The immense potential has been identified by Selex ES. Together, Skyno is now being developed and realised as a fully-operational system. Therefore, this idea and design is clearly a feasible one.

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Appendices

Figures

Tables

Appendix A – Poaching of Rhinoceros

Roots of the problem

<u>South Africa</u>

At the beginning of the 20th century, there were an estimated one million rhinoceroses from four different subspecies that roamed the savannahs of Africa. However, there are several motivating factors that contribute to the killing of wild animals.

In South Africa, the killing of wildlife has been part of their cultural history. In the past, hunting had been a traditional right, as a means to provide food. However, this has evolved, due to the lucrative horns trade. In rural areas, due to the lack of employment opportunities, limited potential for agriculture and livestock production, people often turn towards poaching as a source of income. This has been supplemented by an increasing international demand for horns, which has been long seen as a representation of status and wealth. This resulted in numerous gangs of well-organised professional poachers. These poachers specialise in exploiting the legislative loopholes and vulnerability of the national parks. It is evident that they have been very successful from the sharp decline in rhino populations.

In early 1950s, in China, Mao Zedong strongly advocated and promoted the use of Traditional Chinese medicine (TCM), whilst using it as a means for unifying the country. Among the many claimed "cures" touted was the powdered rhino horn, which was said to cure everything ranging from fever to even cancer.

There was an increasing demand for rhino horns in the Middle East, which are used as ceremonial knife handles. This resulted in a sudden influx of poachers into the African continent. Between 1960 and 1995, an astonishing 98% of the black rhinos were killed by poachers. Although all the rhino species suffered, the western black rhino was hit the hardest.By 1980, the western black rhino could only be found in just two countries: Cameroon and Chad, where an estimated 135 remained. By 1990, they were extinct.

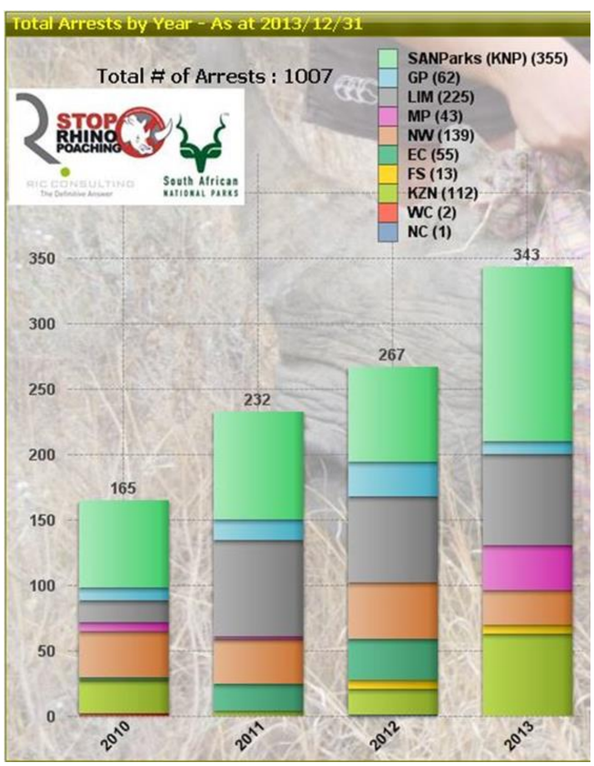

Figure 5: Number of poaching cases in South Africa by the South African Department of Environmental Affairs

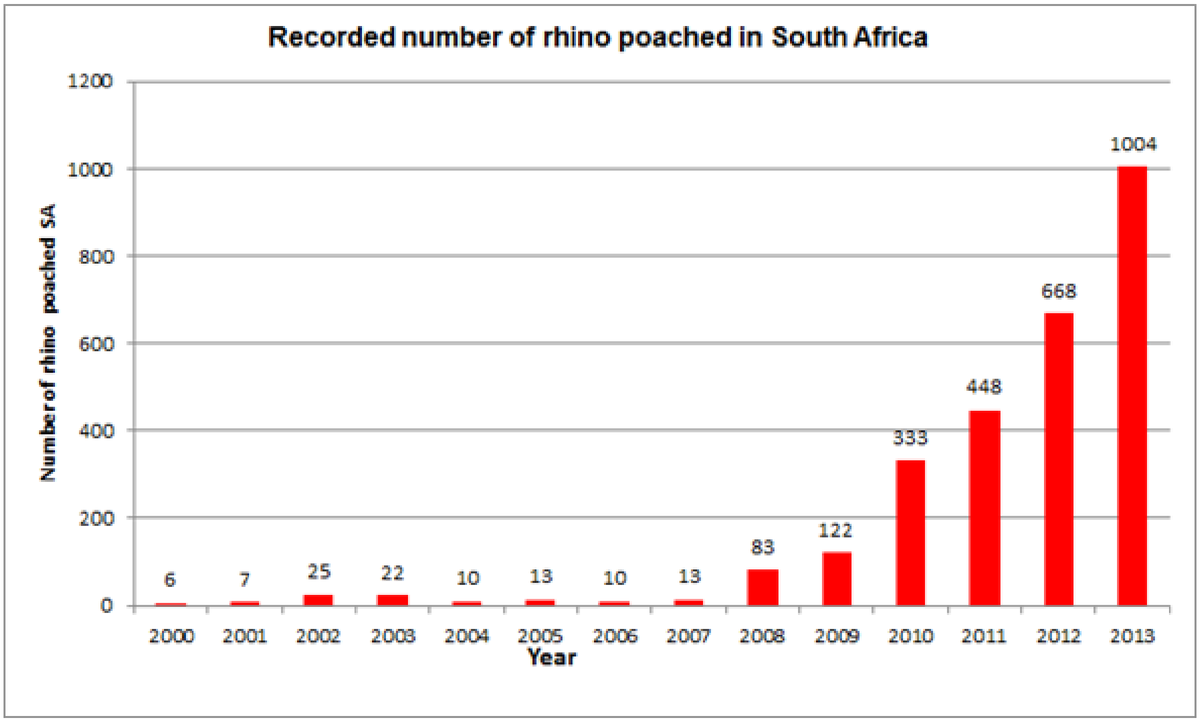

Figure 6: Poaching statistics published by South African Department of Environmental Affairs (2013)

In order to curb the rising trends of poaching, authorities have put in place several measures to combat poaching. Figures released by the South African Department of Environmental Affairs as seen from Figure 1 and Figure 2, shows a steady increase in the number of arrests related to rhino poaching. This could be attributed towards these factors:

- Increasingly severe penalties implemented by the South African government in recent years.
- Increase law enforcement in national parks, with increased frequency of monitoring patrols.
- Educating the public, through community conservation and environmental education schemes
- Captive breeding, relocation and isolation of critically endangered species.

Appendix B - Power

Properties\Methods	Gas-fuelled Generator	Solar Panel System	Lithium Battery
Service hours	At most a day	Throughout the daytime	12 hours
Price	Over £1300	Over £250	£84.95
Weight	Over 60 kg	Over 30 kg	330 g
Advantages	-Easy to implement	-Sustainable -Environmental friendly	-Light weight -High energy density
Disadvantages	-Heavy -Need regular fuel up -Need to step down the voltages for the camera -Noise and air pollution	-Expensive -Heavy	-Need regular charging -Relatively short service hours
Lifespan	3 Years Performance Warranty	10 Years Performance Warranty	500-1000 times of recharging (2 years if recharged everyday)

Table 3: Power Comparison

Skyno Specifications:
Tau 2 Thermal Camera battery rating: 4 - 6 VDC, 1 Wh
Working hours: 12 hours
Power needed for Tau 2 Thermal Camera: 1 Wh x 12 = 12 Wh

Testing Specifications:
GoPro HD Hero3 + Camera Silver Edition battery rating: 1050 mAH, 3.7 V, 3885 mWh,
Working hours: 12 hours
Power needed for GoPro HD Hero3+ Camera Silver Edition: 3885 mWh x 12 = 46.62 Wh

From the above specifications, in order to supply the necessary power for both the Tau 2 as well as the GoPro, it is most feasible to use the lithium batteries. Table 1 outlines the advantages and disadvantages of the various possible methods of powering the system. Generators though easy to implement, are heavy and contribute to pollution. Since the power system is to be included in the payload as well, it is not a feasible solution.

Solar panels can be implemented to provide power. However, solar power is not as efficient. Therefore several panels are required to generate the required power. This makes the overall system extremely expensive. Though possible, it is non-ideal.

Based on the above table, lithium batteries are clearly the solution as they are light and relatively cheap. Also they require little maintenance, making them the logical choice for Skyno.

Battery

There are several types of batteries available in the market nowadays. From Figure 3 below, we can see that lithium batteries have an energy density of 200 - 400 Wh/L, which is higher than most other batteries. The zinc-air battery is not chosen because due to safety considerations and costs incurred. Lithium battery satisfies our needs and it is more readily available.

There are two main types of lithium batteries, namely lithium ion battery and lithium polymer battery. Lithium ion battery has a slightly higher energy density, but it is heavier. In our case, weight is one of the primary factors as the total payload of the system is limited to 1kg. For a similar capacity, lithium polymer battery weighs 330g while lithium ion battery weighs 350g. Lithium polymer battery is preferable as it is 7% lighter.

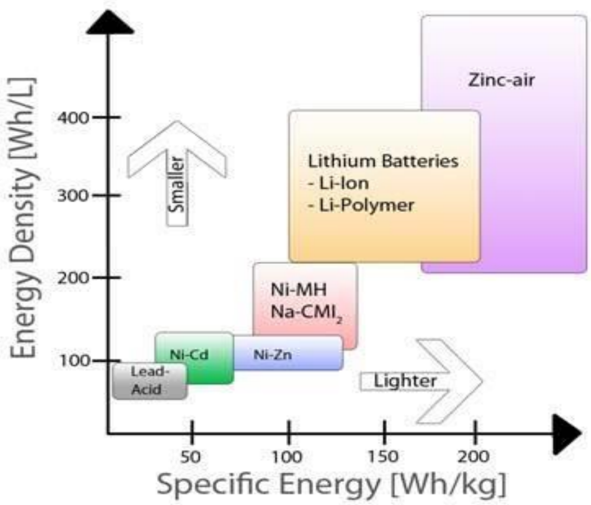

Figure 7: Energy Density Vs Specific Energy

As seen, it is clear that the most feasible power source to use is the Lithium polymer batteries. Even though lithium ion batteries have a higher energy density and is cheaper, weight is more crucial. For this design, therefore, lithium polymers will be used.

Battery Chosen: TRACER 12V 4Ah Lithium Polymer Battery Pack
- Weighs 330 g
- Output at 12V, 4Ah
- Total energy capacity: 12 x 4 = 48 Wh

Appendix C – Stabilisation

Stage 1: Stabilisation of weather balloon (Vertical Axis)
The stabilisation of vertical axis ensures that the weather balloon is maintained at a fixed location at a constant height. This is achieved by tethering the weather balloon securely to the ground using 4 tethering lines.

Stage 2: Rotation of weather balloon (Rotational Axis)
To prevent rotation of the balloon due to winds, the lift of the weather balloon must be large enough to pull the tethering line tight.

Stage 3: Creating a stable flat platform to mount the camera (X and Y axis)
The camera needs to be mounted on a stable horizontal platform to capture sharp images. This is achieved by using a Picavet suspension system.

Stage 4: Software stabilisation
It is not possible to eliminate camera movements completely through the mechanical apparatus. Further video stabilisation is done via software prior to video processing.

Camera Stabilisation

Considerations to tethering are listed below.

1. The weight of the tethering line will take up a large proportion of the lift capacity of the weather balloon.
2. Lines still need to be strong enough to hold down the weather balloon.
3. Height of tethering correlates to ground space required for anchoring.

Considerations of using the Picavet are listed below.

1. Weight of the Picavet; it is ideal that the material used for the Picavet is as light as possible.
2. Strength of platform to hold camera; it is important that the material chosen is still able to hold the weight of the platform as well as able to withstand environmental wearing.

A Picavet works by using the “Equal angle principle”. The weight is maintained at a horizontal plane as it is allowed to slide along the length of a fixed line. This fixed line is attached to the weather balloon. The picavet is attached to the 4 tethering lines.

Whilst the mechanical stabilisation system eliminates major camera shake, it is difficult to remove all movements. Object detection requires the camera to be completely stationary such that the background will be stationary in contrast with the moving objects in the foreground. Video processing techniques is applied to remove this camera shake digitally.

Two methods of accomplishing video stabilisation using MATLAB are documented on their website: the first is to crop away the edge of the video frame which changes due to the camera shake. The resulting central portion of the video frame will be free of translational camera movements. Another method will be to use Point Feature Matching which compares points between frames to correct for camera motion.

The cropping of the image is chosen as it requires less computational power hence reduces the power consumption of the processing unit. In addition, the level of technicality required is lower. Although Point Feature Matching accounts for rotational distortion, the chosen method answers this problem through the mechanical setup of the entire system.

Appendix D –Transmission

Wired and wireless transmission is compared below.

1) Wired Transmission – Cables

I. Coaxial Cables

i) The RG-59 coaxial cable is commonly used at baseband video frequencies, such as composite or component videos. It has a characteristic impedance of 75 Ω, matching the dipole antenna of free space.

ii) The RG-6 coaxial cable is of higher quality as compared to the RG-59. One of the most recognized application of RG-6 is for video signals transmission, carrying either baseband or serial digital interface signals.

Type	Bandwidth/MHz	Attenuation	Advantages	Disadvantages
RG-59	- 5 (Composite) - 10 (Composite) - 300 (High Definition or Digital)	- 3db (50%) at ~200m - 3db (50%) at ~100m - ~20db at 100m	High breakdown voltage	Significant frequency losses, when transmitting over long distance
RG-6	- 1 - 10 - 100 - 1000	- 0.2 - 0.4db at ~30m - 0.6db at ~30m - 2.0db at ~30m - 6.2db at ~30m	Higher tolerances to interference and improved impedance stability	Attenuation of signals will be significant at about 7 MHz

Table 4: Comparison of Wired Transmission

II. VGA Cables

VGA Cables are commonly used to transmit computer graphics to the screen. It is capable of transmitting up to 2048×1536 pixels (QXGA) at 85 Hz (388 MHz).

III. DVI Cables

DVI cables carry a digital video signal; hence the signal does not deteriorate over distances. It all depends on whether the signal is able to reach the receiving end of the cable.

IV. HDMI Cables

A HDMI cable carries digital video in a similar manner to DVI, with the added capability of audio signal as well. Therefore the video transmission characteristics are comparable to that of DVI. It provides reliable performance at 5m.

Type	Resolution/pixels	Maximum length/m
VGA	- 1280 x 1024 and lower - 1600 x 1200 and above	- 30 - 1
DVI	- 1280 x 1024 and lower - 1280 x 1024 and above	- 15 - 5
HDMI	- 1920 x 1080 and above	~ 10

Table 5: Comparison between different cables

Based on the table 3, it can be seen that the maximum lengths of the cables fall short of the design requirements. Since Skyno will be flown at a height of about 100m, boosters are required.

Bolstering Transmission flexibility

Signal Boosters or Amplifiers

Using active components like amplifiers to boost the signal is not a good option. Amplifying a signal along the transmission channel amplifies noise as well, hence signal quality is not improved as the signal to noise ratio remains the same. Furthermore, the active components need to be powered requiring power sources or supply cables to be placed alongside the amplifiers.

1. VGA Extender via Ethernet Cables

   Ethernet cables such as the Category 5/5E cables consist of pairs of wires carrying equal and opposite signals that are twisted together. This twisting assists in cancelling out electromagnetic interference. These cables also have lower losses at higher frequencies. The maximum standard length for Ethernet cables is 100m; signal quality is not assured when beyond that length.

   Through the use of an adaptor to generate twisted pair signals from the VGA signal, the VGA video can be transmitted via Ethernet cables for longer distances. Another adaptor however is needed at the receiving end to convert the signal back to VGA format.

2. DVI/HDMI Extenders via Ethernet Cables

   These extenders work in the same way as the VGA extender. They are however, generally more expensive than VGA extenders with the same extension range.

3. Fibre Optics

   Optic fibres are able to carry a high bandwidth signal over long distances. The only issue is cost as optic fibres are very expensive compared to copper cables.

   Optic fibres carry a digital signal which can be used with digital video interfaces like DVI and HDMI. It can also be used with VGA with the transmitter doing an analogue to digital conversion of the signal. Hence it can act as an extender for these video signals. Optic fibres extenders can comfortably increase the transmission distance to a 1000m and beyond.

	Signal Boosters	VGA Extenders	DVI/HDMI Extenders	Optic Fibers
Pros	• Single Cable • No need for adaptors	• Longer VGA distances (up to 1000ft. or 300m)	• Longer DVI/HDMI distances (up to 330ft. or 100m)	• Very long transmission distances (1000m and above)
Cons	• Power Supply required • Not effective	• Power supply required for transmission and receiving adaptors	• Power supply required for transmission and receiving adaptors • Expensive extenders	• Both extenders and cable are expensive

Table 6: Pros and Cons of various range extenders

Summary

Despite having boosters in wired transmission, it is less than ideal because firstly the weight of the wires will contribute to the payload weight. There is also an increased chance of lightning strikes the wires will be grounded, making the system less reliable. Multiple boosters will also be required when the balloon is deployed at a height of 120m. Therefore wireless transmission needs to be considered.

2) Wireless Transmission

Most wireless transmission requires the examination of the frequency spectrum. Certain transmitters within a medium can transfer either analogue or digital signals.

Limitations

South Africa regulates its frequency spectrum regularly and there is only a select range of frequencies that are available. This primarily ranges from 2.4 GHz – 10 GHz. However, at select frequency ranges, between these two values, there may be interference from other networks. These limits allow few reliable wireless systems to be considered:

- Terrestrial microwave systems
- Satellite microwave Systems
- Radio Waves

Wireless transmission methods

Type of System	Microwave	Satellite Microwave	Radio Transmission
Bandwidth/MHz	Proportional to data rate (220 MHz = 274 Mbps)	3.7 - 4.2 GHz	-
Frequency Range (Omni-directional)	1 GHz - 40GHz	1 GHz - 10 GHz (Optimum Range)	3 - 30 GHz (SHF)
Signal Beam	Narrow Beam	Narrow Beam	Omni-directional
Common Antenna	Parabolic Dishes	Parabolic Dishes	Small Linear Antennae
Relationship of loss of Signal	Inversely proportional to square of distance	No Relationship but severely impaired by other transmissions	Inversely proportional to square of distance
Rainfall Effect	Signal impaired above 10 GHz		
Cost	Expensive ($2000) but cheaper for higher frequencies (22GHz and above)	Most Expensive out of all solutions (~$5000)	Cheapest Solution

Table 7: Comparison between different wireless systems

I. Microwave Systems

Short range microwave systems work effectively to transmit videos. However, they are not cheap, and may interfere with the band range of frequencies used in mobile phone or TV networks. Attenuation varies with square of distance.

II. Satellite microwave systems

This technology provides point to point linkage with multiple receivers, requiring the leasing of channels from companies. Therefore making this option the most effective in providing noise immunity and coverage, whilst opening up further scopes to our project. It is, however, the priciest out of all the methods.

III. Radio Transmission

This method allows omni-directional transmission (as opposed to point to point) which provides the greatest flexibility for the receiver. It also means that the antennas will not have to be disked shape and require alignment.

Summary

It can be concluded that the radio transmission will be the most effective solution. It allows for the most flexibility as it does not need the receiver to point directly to the transmitter. It is also the most cost effective solution. After identifying the best system to employ, the next step is to identify which radio frequency to use.

Further Research into chosen transmission

There are four main frequencies that are produced by most manufactures. By South African law only the two can be used:

- 2.4 GHz
- 5.8 GHz

	2.4 GHz	**5.8 GHz**
Pros	• Low cost • Availability of modification components	• Resistance to interference in the bands • 4 channels • Require small antennas • Wide effective range of up to 4 km • Small and light
Cons	• Require larger antennas • Prone to interference • Limited effective range of 200 - 700 ft.	• Line of sight operation

Table 8: Advantages and Disadvantages of Frequencies

From this table, we can see that there may be possible interference from other 2.4 GHz networks. Although the area of operation is not in an urban area, it is a worthwhile consideration. Hence the 5.8 GHz seems a more viable solution.

Increasing range with 5.8 GHz

It is worthwhile to consider how to increase the range to a maximum without compromising quality. This could easily be done by increasing power but this does not directly correspond to increasing range. In addition it has to be balanced with the legal and design limitations of the system.

The antenna is the ideal way the range can be increased. Its effectiveness can be more significant than increasing transmitting power.

Range has to be increased in every direction. Omnidirectional antennas are preferred over linearly polarised ones.

Antenna Gain

A clover leaf antenna can be used which radiates in every direction thus allowing maximum flexibility. However, to obtain a further range we can use a configuration of helical and clover leaf antennas.
Helical antenna increases the gain many times. However, this is at the expense of radiating in every direction:

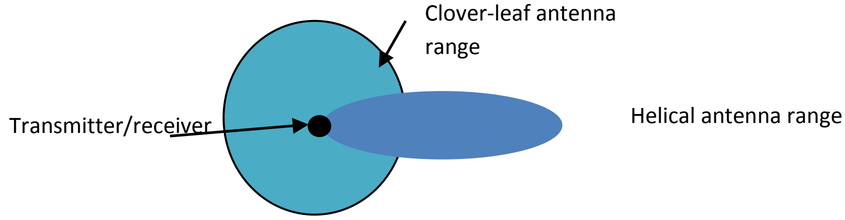

Figure 8 : Single Antenna Range

By designing a carefully constructed circuit we can use up to four antennas on a receiver. When one is out of range, the other antenna can switch on:

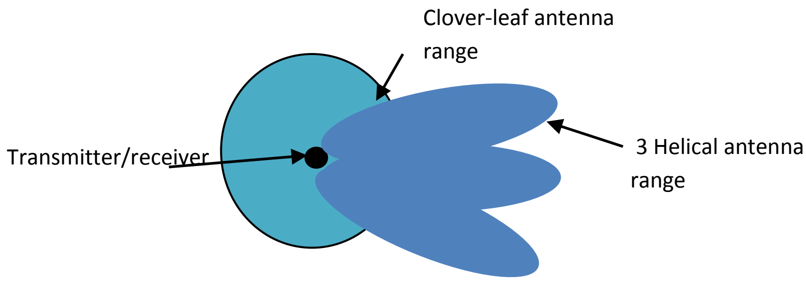

Figure 9: 3 Antenna Range

Appendix E –Weather balloon

Balloon Weight (gr)	200	300	350	450	500	600	700	800	1000	1200	1500	2000	3000
Diameter at Release (cm)	117	123	125	130	133	142	146	150	157	179	185	195	212
Volume at Release (cu.m)	0.83	0.97	1.03	1.1	1.22	1.5	1.63	1.76	2.01	2.99	3.33	3.89	4.97
Gross Lift (gr)	960	1110	1185	1335	1405	1720	1870	2020	2310	3440	3830	4470	5720
Nozzle Lift (gr)	760	810	835	885	905	1120	1170	1220	1310	2240	2330	2470	2720
Payload (gr)	250	250	250	250	250	250	250	250	250	1050	1050	1050	1050
Recommended Free Lift (gr)	510	560	585	635	655	870	920	970	1060	1190	1280	1420	1670
Rate of Ascent (m/min)	320	320	320	320	320	320	320	320	320	320	320	320	320
Diameter at Burst (cm)	300	378	412	472	499	602	653	700	786	863	944	1054	1300
Volume at Burst (cu m)	14.1	28.3	36.6	55.1	65.1	114.2	145.8	179.6	254.3	336.5	440.5	613.1	1150.3
Bursting Altitude (km)	21.2	24.7	25.9	27.7	28.4	30.8	31.8	32.6	33.9	33.2	34.2	35.4	37.9

Table 9: Weather Balloon Specifications

The above table shows the various factors concerned with the TOTEX weather balloons used for Skyno. To meet the specifications of the payload, a balloon which is capable of lifting a payload of 1000g is chosen. In this case, the balloon of weight 1200g and a gross lift of 3440g is selected. This balloon meets the minimum requirements needed for this project and hence was decided to be ideal.

The balloon can be filled with either Helium or Hydrogen to generate lift. The general considerations of both gases are listed below.

Helium

- Inert gas and does not pose much of a safety hazard
- Expensive to obtain pure helium

Hydrogen

- Highly combustible gas and can cause fires or explode

Based on the Archimedes' principle, a body immersed in a fluid experiences a buoyant force equal to weight of fluid it displaces. This is dependent on the various densities of the gases at standard temperature and pressure (STP) which is 300K and 1 atm respectively. The molar masses of air, helium and hydrogen are 29.0 g/mol, 4.00g/mol, 2.016 g/mol respectively.

$$PV = nRT$$

$$where\ P = pressure, V = volume, n = number\ of\ moles\ of\ gas,$$

$$R = Universal\ Gas\ constant\ , T = temperature$$

$$\frac{n}{V} = \frac{P}{RT}$$

Therefore under STP conditions,

$$\frac{n}{V} = \frac{1}{0.08206 * 300} = 0.04062\ mol/l$$

With these figures the densities of these 3 gases can be calculated by substituting the molar masses into the third equation above. Therefore the densities of air, helium and hydrogen are 1.18 g/l, 0.164g/l and 0.0855 g/l.

It can hence be concluded

$$1\ l\ of\ Helium\ can\ lift\ = 1.18 - 0.164 = 1.016g$$

And

$$1\ l\ of\ Hydrogen\ can\ lift\ = 1.18 - 0.0855 = 1.0945g$$

For this project, helium will be used because it is a safer alternative as compared to hydrogen though it has a lower lift capability and may be more expensive. The above figures shown in the table are for hydrogen and not helium. Hence some conversion needs to done to determine the amount of helium required for Skyno.

Based on the table, roughly 2.99 cubic metres of hydrogen is required to generate the required lift. Hence,

$$Weight\ lifted\ by\ hydrogen = (2.99 * 1000) * 1.0945$$

$$= 3272.55\ g$$

$$Volume\ of\ helium\ required = \frac{3272.55}{1.016}$$

$$= 3221.01\ litres$$

$$= 3.221\ m^3$$

To generate sufficient lift for this design, 3.221 cubic metres of helium is required.

Appendix F – Video Processing

There are a few strategies to track moving objects in a video. Strategies are chosen based on the capability of the software used. OpenCV is an open source computer vision library which features many image processing functions compatible with C++. Image processing toolbox and computer vision toolbox add-ons found in MATLAB can also be used to implement object tracking.

Since OpenCV is typically implemented in C++ and is designed for fast processing, the image processing application will execute faster than an application that uses MATLAB. However MATLAB provides an easier programming environment which requires less time spent on programming and debugging. Fast implementation of code in this project is more appealing at the current project stage (feasibility analysis) because the aim is to assess which strategy for tracking objects will work well in the proposed system. Therefore MATLAB is chosen as the programming environment instead of OpenCV for this stage.

MATLAB – Object Tracking Using Gaussian Mixture Models

This method of object tracking uses Gaussian mixture models to differentiate the background from the foreground in a video. Gaussian mixture model is a probability density function, $p(\mathbf{X})$. It comprises of a weighted sum of Gaussian component densities, $g(\mathbf{X})$.

$$p(\mathbf{x}|\lambda) = \sum_{i=1}^{M} w_i \, g(\mathbf{x}|\boldsymbol{\mu}_i, \boldsymbol{\Sigma}_i)$$

$$g(\mathbf{x}|\boldsymbol{\mu}_i, \boldsymbol{\Sigma}_i) = \frac{1}{(2\pi)^{D/2}|\Sigma_i|^{1/2}} \exp\left\{-\frac{1}{2}(\mathbf{x}-\boldsymbol{\mu}_i)' \, \Sigma_i^{-1} \, (\mathbf{x}-\boldsymbol{\mu}_i)\right\}$$

Being able to represent distributions with arbitrary shapes, this probability function is commonly utilised to model the history of the intensity of each pixel in the video frame. This model is able to adapt to gradual changes and represents multi-modal backgrounds such as one with swaying trees.

The parameters of the Gaussian mixture model are defined through a set of training data which, in this case, will be the first few frames of the video. In the computer vision toolbox, the *foreground detector* function initialises the Gaussian mixture model for detecting the foreground. The foreground detector gradually learns and subtracts away the background over 50 initial frames.

Once the foreground detector has learned to identify the background, a morphological filter is applied to remove the noise in the resultant foreground image frame. Moving objects which are not part of the static background will then be registered as a blob of white pixels in the black image frame. Using MATLAB function *blob analysis* and specifying the minimum and maximum blob sizes, will allow us to set the threshold size of the object that we want to detect. After the detection of the moving object, a highlighting green box is imposed around the object in the image frame and a counter keeps track of the number of moving objects in the video.

This strategy is obtained from a MATLAB demonstration on the MathWorks Website. To assess its suitability to our project, the program was adapted for real-time video processing. The code is shown below.

```matlab
% Real Time Moving Object Detection using Webcam
%   modified from DETECTING CARS USING GAUSSIAN MIXTURE MODELS DEMO
%   obtained from "http://www.mathworks.co.uk/help/vision/
%   examples/detecting-cars-using-gaussian-mixture-models.html"
%           additional comments by Sze Kiat Tan

% Initialise Foreground Detector with 3 Gaussian modes and 50 initial
% video frames for training background model
foregroundDetector = vision.ForegroundDetector('NumGaussians', 3, ...
    'NumTrainingFrames', 50);

% Train the foreground detector to determine whether a pixel is part of a
% background or foreground
%videoReader = vision.VideoFileReader('Traffic.mp4');
videoReader = imaq.VideoDevice('winvideo', 1, 'MJPG_640x480');
for i = 1:150
    frame = step(videoReader); % read the next video frame
    foreground = step(foregroundDetector, frame);
end

figure(1);
subplot(2,2,1);
imshow(frame); title('Video Frame');
subplot(2,2,2);
imshow(foreground); title('Foreground');


% ===== Analyse the initial frame ========================================

% Filters the foreground
se = strel('square', 3);
filteredForeground = imopen(foreground, se);
subplot(2,2,3);
imshow(filteredForeground); title('Clean Foreground');


    % Sets the BlobAnalysis Properties
blobAnalysis = vision.BlobAnalysis('BoundingBoxOutputPort', true, ...
    'AreaOutputPort', false, 'CentroidOutputPort', false, ...
    'MinimumBlobArea', 900, 'MaximumBlobArea', 40000);
    % Returns bounding box of blobs found in 'filteredForeground'
bbox = step(blobAnalysis, filteredForeground);

result = insertShape(frame, 'Rectangle', bbox, 'Color', 'green');

    % Counts the number of cars
numCars = size(bbox, 1);
result = insertText(result, [10 10], numCars, 'BoxOpacity', 1, ...
    'FontSize', 14);

subplot(2,2,4);
imshow(result); title('Detected Objects');
```

Figure 10: MATLAB Code

```
% ===== Process the rest of the video ====================================

videoPlayer = vision.VideoPlayer('Name', 'Detected Cars');
videoPlayer.Position(1:4) = [100, 100, 1300,750];  % window size: [width,
height]
videoPlayer2 = vision.VideoPlayer('Name', 'Foreground');
videoPlayer2.Position(1:4) = [50, 50, 1300,750];  % window size: [width,
height]
se = strel('square', 3); % morphological filter for noise removal

k = 0; % initialise counter
uport = udp('127.0.0.1',4012); % set up UDP port

while k < 5e3;

    frame = step(videoReader); % read the next video frame

    % Detect the foreground in the current video frame
    foreground = step(foregroundDetector, frame);

    % Use morphological opening to remove noise in the foreground
    filteredForeground = imopen(foreground, se);

    % Show Filtered Foreground Video Feed
    step(videoPlayer2, filteredForeground);

    % Detect the connected components with the specified minimum area, and
    % compute their bounding boxes
    bbox = step(blobAnalysis, filteredForeground);

    % Draw bounding boxes around the detected cars
    result = insertShape(frame, 'Rectangle', bbox, 'Color', 'green');

    % Display the number of cars found in the video frame
    numCars = size(bbox, 1);
    result = insertText(result, [10 10], numCars, 'BoxOpacity', 1, ...
        'FontSize', 14);

    step(videoPlayer, result);  % display the results

    k = k+1; % updates the counter

    % Sends number of detected cars via UDP to the SKYNO Client
    UDPsend(numCars , uport);

end

release(videoReader); % close the video file
release(videoPlayer);
release(videoPlayer2);
```

Figure 11: MATLAB Code Part 2

Appendix G – Skyno Java Client (Beta Version)

The Skyno Client intergrates information from multiple Skyno units into a graphic display to acting as a simple alert mechanism for the user. The figure below showcases the Skyno user interface developed using Java.

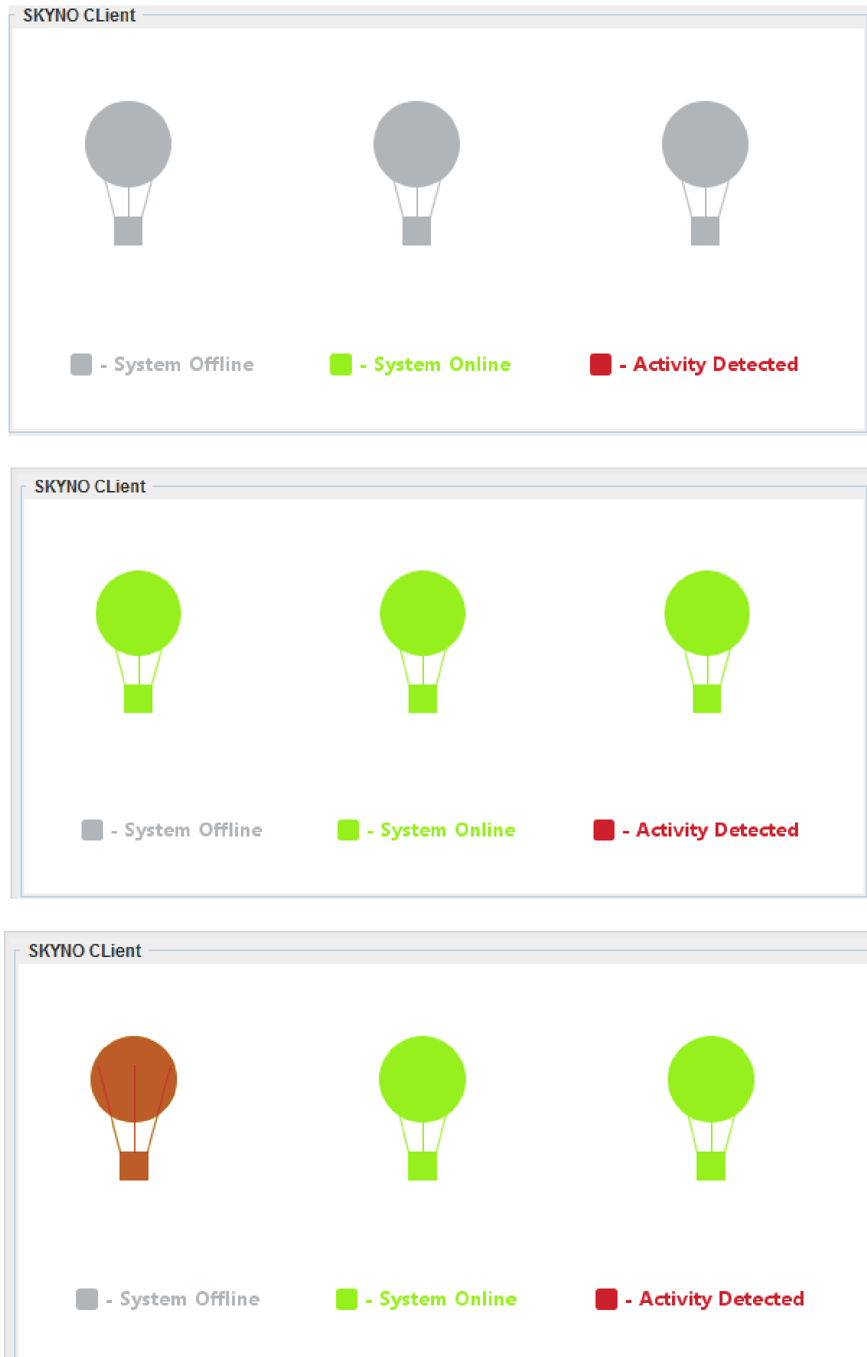

Figure 12: Different states of Skyno Client

Skyno Client uses a UDP connection which is suitable as it is a minimalistic transfer protocol since error correction is not necessary for the data being sent over the Skyno network. The Java utility for receiving UDP packets is shown below.

```
/*UDP client utility for SKYNO Client
 *
 *                      Used in conjunction with 'SKYNOClient'
 *                              Author                  : Tan Sze Kiat
 *                              Date updated        : 17th February 2014
 *                              Version                 : 1.0b
 *
 * */
import java.net.*;
import java.io.*;

class UDPClient {

        UDPClient(Display d){
                        DatagramSocket Socket = null;
                        try {
                                double[] SKYNOdata = new double[8];

                                while(true)                     //loop for data updating automatically
                                {
                                        //declarations of port number
                                        Socket = new DatagramSocket(4012);
                                        //Set Socket time limit to shift to Exception
                                        Socket.setSoTimeout(60000);
                                        Socket.setReuseAddress(true);
                                        //Set packet length upper limit
                                        byte[] packetLength = new byte[200];

                                        //create receive packet
                                        DatagramPacket recv_packet = new DatagramPacket(packetLength, packetLength.length);
                                        //receive packet from Socket
                                        Socket.receive(recv_packet);
                                        //close Socket inside loop to avoid Socket error
                                        Socket.close();
                                        //get data and store in mssg
                                        byte[] mssg = recv_packet.getData();
                                        //convert byte[] mssg to String
                                        String received= new String(mssg);
                                        //separate the parameters
                                        String[] array = received.split("-");

                                        // conversion of received data into double
                                        for( int i=0; i<array.length; i++)    {
                                                SKYNOdata[i] = 0;
                                                SKYNOdata[i] = Double.parseDouble(array[i]);
                                        // System.out.println("Parameter" + i + ": "+ array[i]+" ; "); //Uncomment to debug data stream
                                        }

                                        // call on SKYNO Client display to display the information
                                        d.setlevel(SKYNOdata);
                                }
                        }

                        //Clarify the Exceptions
                        catch (SocketException e) {
                                System.out.println("Socket: " + e.getMessage());
                        }
                        catch (IOException e) {
                                System.out.println("IO: " + e.getMessage());
                        }

                }

}
```

Figure 13: Alert System Code

Appendix H – Video Camera

Pixel resolution vs Altitude

As the system aims to maximise the area monitored, the balloon should be flown at high an altitude as possible with a lens that provides the largest Field Of View possible. However, flying the balloon at a higher altitude introduces a trade-off in pixel resolution. Pixel resolution, the number of pixels which the target object occupies, reduces with higher altitudes. Therefore, analysis has to be conducted to determine the maximum altitude which the balloon can be flown at to maximise the area monitored whilst maintaining a minimum pixel resolution for successful detection by the software. Sensors on cameras have different pixel counts along the horizontal and vertical axis thus, analysis will be conducted separately along these horizontal and vertical axis.

Horizontal

By proportion,

$$\frac{L_o}{L_{monitored}} = \frac{P_o}{P_{total}}$$

L_o = Horizontal length of object
$L_{monitored}$ = Horizontal length monitored
P_o = Number of pixels occupied by the detected object
P_{total} = Total number of pixels in the horizontal axis
Rearranging the equation,

$$L_{monitored} = \frac{L_o P_{total}}{P_o}$$

To calculate the maximum $L_{monitored}$ while maintaining a minimum pixel resolution, an inequality is introduced instead.

$$L_{monitored} < \frac{L_o P_{total}}{P_o}$$

With the maximum $L_{monitored}$ determined by the above equation, the maximum altitude which the balloon can be flown at can be determined.

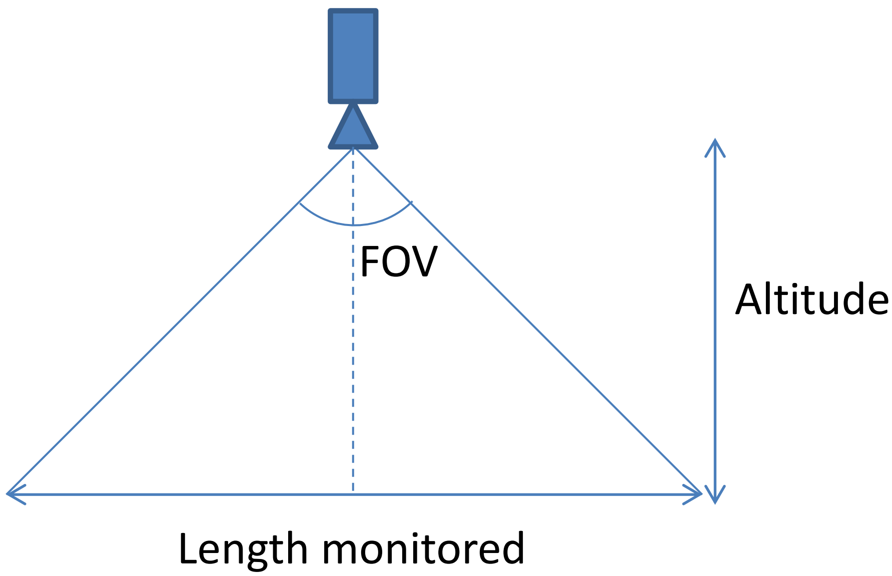

Figure 14: FOV Diagram

The relationship between Field Of View and length can be determined through trigonometry,

$$\tan\frac{\propto}{2} = \frac{L_{monitored}}{2A}$$

$\propto$ = Field Of View
A = Altitude
Rearranging the equation with $L_{monitored}$ as the subject,

$$L_{monitored} = 2A \tan\frac{\propto}{2}$$

Substituting this equation with inequality (1),

$$2A \tan\frac{\propto}{2} < \frac{L_o P_{total}}{P_o}$$

To determine the maximum altitude which the balloon can be flown at, the inequality can be rearranged with A as the subject,

$$A < \frac{L_o P_{total}}{2 P_o \tan\frac{\propto}{2}}$$

To ensure for the successful detection of the target vehicle, the number of pixels occupied by the detected object P_o has been set at 5 along a single axis. The dimensions of a Range Rover of approximately 4.5m * 2.5m have been chosen as the benchmark for vehicle detection. Taking into account the worst case scenario where only the short side of the vehicle can be seen. Considering the lowered quality of the video feed due to transmission noise, a block of 2m * 2m is taken as the design benchmark. Therefore, the maximum altitude at which the balloon can be flown at is plotted with respect to its Field Of View across various camera resolutions using the above inequality, with

$P_o = 5$
$L_o = 2m$

The graph of

$$A = \frac{(2)P_{total}}{2\ (5)\ \tan\frac{\propto}{2}}$$

is thus plotted with respect to Field Of View at video resolutions of 128p, 240p, 320p, 480p, 512p, 720p, 1080p.

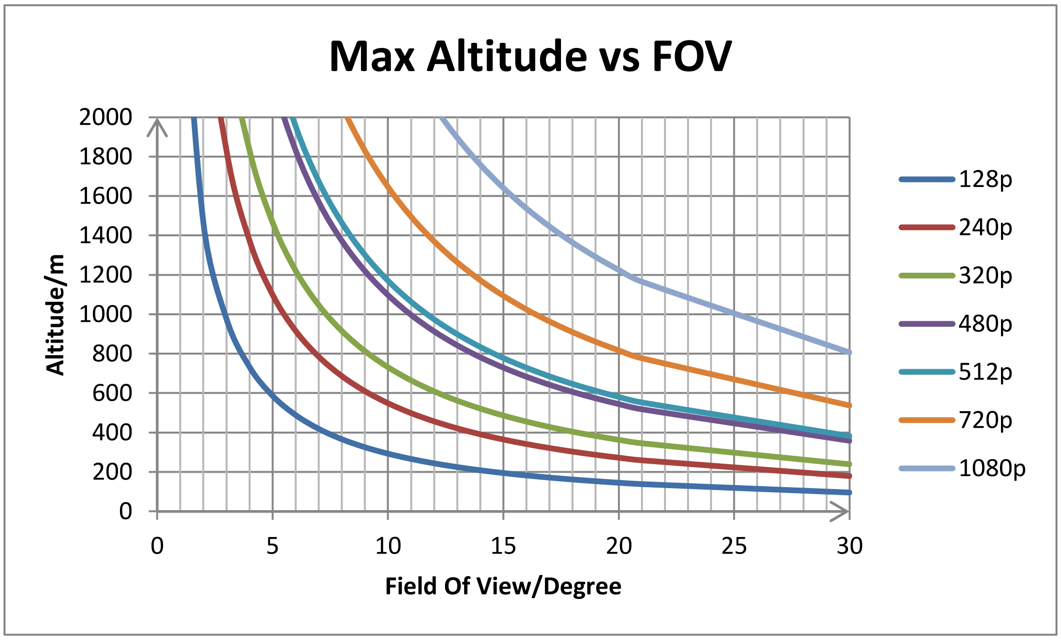

Figure 15: Max Latitude Vs FOV for various video resolutions

The graph above illustrates that a camera with high resolutions such as 1080p would be wasteful as even though the maximum altitude is increased greatly, flying the system at such an altitude would expose the system to other environmental effects. Furthermore, Skyno aims to utilize thermal imaging. In this design a low resolution camera is used as high resolution thermal cameras are expensive and have high power consumption. Therefore a thermal camera with a resolution of 128p is sufficient to monitor a reasonable area while still maintaining the required pixel resolution.

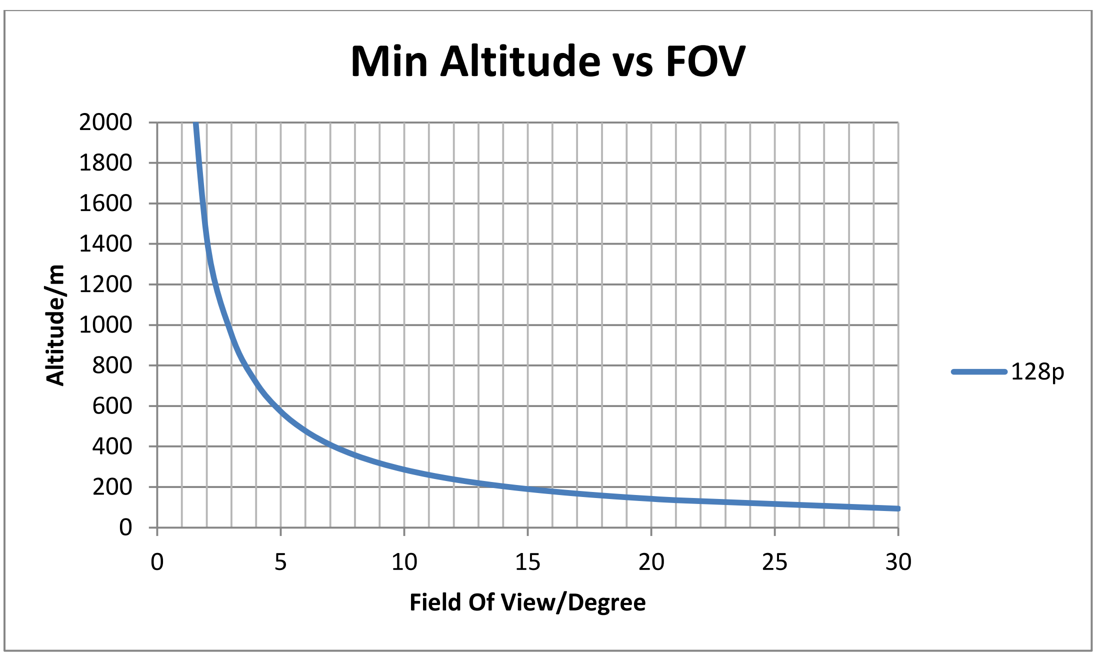

Figure 16: Min Altitude Vs FOV for 128p camera

The graph above shows the minimum altitude the balloon has to be flown for a 128p camera to capture an effective area of 50*50m and at the same time maintain an effective pixel density of the target concerned.

The equation used is

$$A = \frac{50}{2\ \tan\frac{\propto}{2}}$$

Hence we have obtained the maximum and minimum heights at which a 128p camera can be flown at various FOV lenses. The Tau2 is chosen as a suitable camera as it is a thermal camera capable of meeting our system requirements. As seen the above graph, as the FOV decreases, the minimum altitude increases.

The Tau2 low resolution camera has only a few types of FOV lenses. In this design, we will be using the 7.5mm lens which has a FOV of 30*24 degrees. Based on these specifications, accurate measurements can be taken as shown below.

Horizontal

Assuming that the dimension of the vehicle to be detected is 4.5m x 2.5m and substituting the specifications of the camera chosen, Tau2 160 with a 7.5mm lens, while maintaining a P_o at least 5 for successful detection by the algorithm,

L_o = 4.5m
P_{total} = 160 pixels
P_o = 5 pixels
$\propto$ = 30 degrees

$$A < \frac{(4.5)(160)}{(2)(5)\ \tan\frac{30}{2}}$$

$$A < 268.7m$$

Vertical

The analysis can be repeated for the vertical axis with changes in P_{total} and $\propto$ due to the specifications of the Tau2 160.

L_o = 4.5m
P_{total} = 128 pixels
P_o = 5 pixels
$\propto$ = 24 degrees

$$A < \frac{(4.5)(128)}{(2)(5)\ \tan\frac{24}{2}}$$

$$A < 271\ m$$

Therefore, theoretically, the maximum altitude which the balloon can be flown is 268.7m. This would allow effective surveillance of an area of 143m x 114m.

However, in the worst case where only the short side (2.5m) of the vehicle can be seen and taking into account the introduction of noise which would affect video quality, the analysis will be conducted with the following variables.

Horizontal:

L_o = 2m
P_{total} = 160 pixels
P_o = 5 pixels
$\propto$ = 30 degrees

$$A < \frac{(2)(160)}{(2)(5)\ \tan\frac{30}{2}}$$

$$A < 119.4\ m$$

Vertical:

L_o = 2m
P_{total} = 128 pixels
P_o = 5 pixels
$\propto$ = 24 degrees

$$A < \frac{(2)(128)}{(2)(5)\ \tan\frac{24}{2}}$$

$$A < 120.4\ m$$

Therefore, to maintain a pixel resolution of 5 for the vehicle to be successfully detected, the maximum altitude which the balloon can be flown at is 119.4m, allowing for the surveillance of an area of 64m x 50.8m.

Minimum Altitude:

$$A > \frac{(50)}{(2)\ \tan\frac{24}{2}}$$

$$A > 117.6\ m$$

The above calculation shows the minimum altitude required to effectively monitor an area of 50m * 50m.

However, to introduce some buffer and to ensure that the vehicle is successfully detected, coupled with other considerations such as the presence of winds at a higher altitude and the length of the tethering lines required, an altitude of 120m is chosen, allowing for the effective surveillance of an area of 64m x 51m.

Appendix I– Tethering Lines

Due to the requirements of the mechanical stabilisation—the Picavet—to have 4 anchor points, 4 tethering lines will be used to tether the balloon to the ground. The 4 lines will be anchored at an angle to the balloon to provide lateral forces to counter any rotational movement of the balloon. The diagram below shows two options for anchoring the lines (2-D view); the lines are tethered outwards in the first option and tethered inwards in the second option.

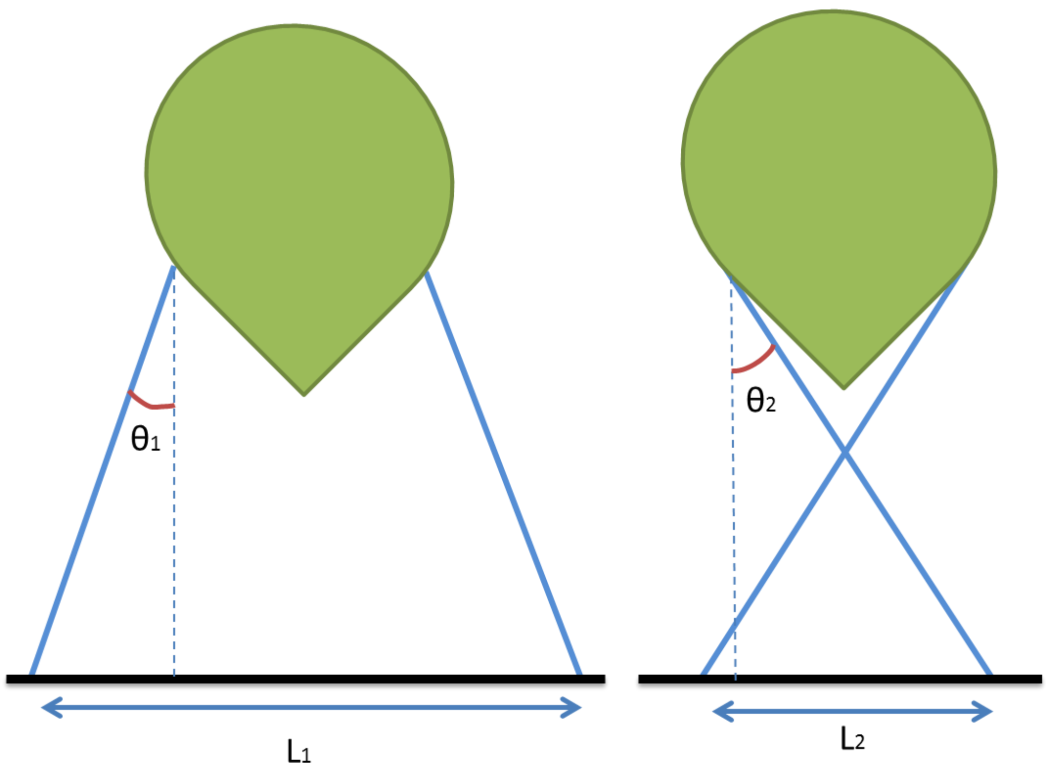

Figure 17: Line Tethering Options for the Skyno Balloon

As seen from the above figure, option 2 is more advantageous over option 1 as it conserves ground space, L. Hence a larger anchor angle, θ, can be obtained in the same amount of ground space when using option 2 and vice versa if holding the anchor angle constant. However the issue with option 2 is that the crossing of the lines at the centre may generate rotational moments.

<u>Ground Space Calculation</u>

Consider the Totex balloon at a height of 120m with a diameter of 1.79m being anchored at 15°:

$$L_1 = 2 \times 120 \times \tan\theta_1 + 1.79 = 66.10m$$
$$L_2 = 120 \times \tan\theta_2 = 32.15m$$

where $\theta_1 = \theta_2 = 15°$

Hence it can be seen that the ground space required by the tethering line anchors is substantially larger than the diameter of the balloon, even when choosing option 2 and using a small anchor angle. Skyno will currently be adopting option 1.

The material used for the tether must be strong, weather resistant and lightweight. Kevlar® is the material of choice as it fulfils all the mentioned properties. Kevlar® is best known as the fabric used in making bulletproof vest but it is also used as high performance line for kite flying.

Kevlar® Line Calculations

Consider the Totex balloon weighing 1.200kg with a 1.000kg payload resulting in a free lift of 1.190kg:

$$F_{Up} = \frac{1.190 \times 9.98}{4} = 2.96905N$$

$$F_{Line\ @\ 15°} = \frac{F_{Up}}{\cos 15°} = 3.07379N$$

A Kevlar® twisted line with breaking strength of 70lbs or 31.75kg can withstand a force of $31.75 \times 9.98 = 316.65N$ which is more than sufficient to withstand the uplift of the balloon. The additional strength of the line is used to support the balloon in windy conditions. Kevlar® line is also resistant to cuts and hence offers some degree of protection against tampering.

Consider Totex balloon at a height of 120m with 4 tethering lines anchored at 15°:

$$Line\ Length_{Total} = \frac{120}{\cos 15°} \times 4 = 496.93m$$

$$Line\ Weight_{Total} = 496.93m \times \frac{0.01842kg}{100m} = 0.0915kg$$

As seen, the Kevlar Line is very lightweight which is crucial as it will not diminish the lift of the balloon too significantly and reduce tension in the line.

Appendix J - Durability

The Skyno unit would be enclosed in a PVC tube filled with sponge cushioning. The purpose of enclosing the unit is to fulfil these criteria:

a) Impact resistant
b) Waterproof

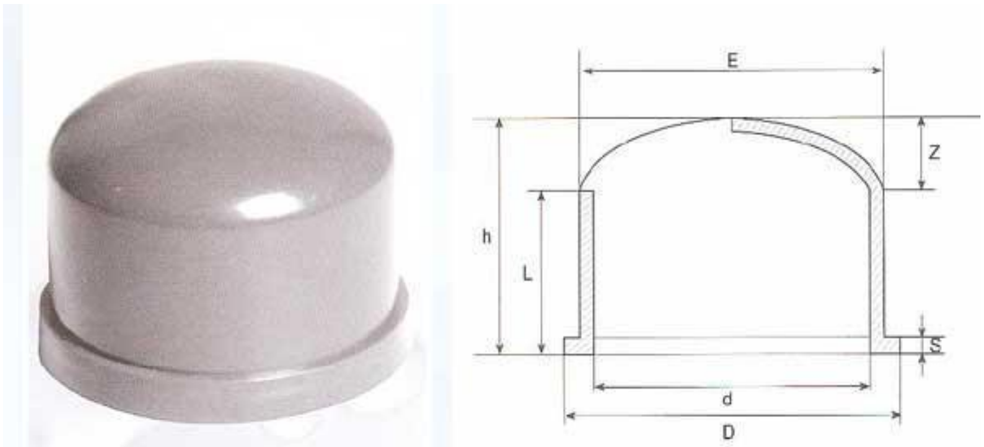

Figure 18: PVC enclosure and cross-section diagram

Strength is an indication of how much force the material can support, while toughness indicates how much energy a material can absorb before rupturing. The desired PVC used has to be tough, being both strong yet ductile. Thus, it should be able to withstand high stresses and strains.

The PVC pipe will be fitted with foamed end caps, wrapped with bubble pack. The amount of shock transmitted by a particular cushioning material is largely dependent on the thickness of the cushion, drop height and the load-bearing area of the cushion.

The cushion must deform under shock for it to function. Based on the cushion curves, we will be using a recommended two to three inches of cushioning.

Factors of Concerns

We will be taking into account several factors, which are crucial in determining the durability required of the PVC enclosure. The factors are as follows:

Velocity upon impact (v)

$$v = \sqrt{(v_0^2 + 2gs)}$$

where:

v = velocity upon impact (ft/s)
v_0= initial velocity (ft/s)
g = acceleration due to gravity (32.2 ft/s^2)
s = distance of the fall (ft)

Rate of deceleration (a)

$$a = v^2/2d$$

where:

a = rate of deceleration (ft/s^2)
v = the velocity at the point of impact (ft/s)
d = deceleration distance (ft)

Time to fall (t), based on the distance of fall (s)

$$t = \sqrt{(2s/g)}$$

where:

t = time (s)
s = distance (ft)
g = acceleration due to gravity (32.2 ft/s^2)

Force of impact F_i

$$F_i = \frac{Wa}{g} = WG$$

where:

F_i = force of impact (pounds force)
W = object weight (lbs)
a = rate of deceleration (ft/s^2)
g = acceleration due to gravity (32.2 ft/s^2)
G = G-force

The distance of focus will be from 100 to 200m, which approximates to 328 to 658 feet.

Distance of Fall (ft)	Velocity on Impact (ft/s)	Deceleration Distance (ft)	Rate of Deceleration (ft/s^2)	Weight (lbs)	Force of Impact (lbs-force)	Time (s)
164.0419948	102.7828024	0.020833333	253543.3071	2.204622622	17359.23324	3.192012496
196.8503937	112.5929188	0.020833333	304251.9685	2.204622622	20831.07989	3.496674496
229.6587927	121.6142518	0.020833333	354960.6299	2.204622622	24302.92654	3.776840119
262.4671916	130.0111039	0.020833333	405669.2913	2.204622622	27774.77319	4.037611923
295.2755906	137.8975998	0.020833333	456377.9528	2.204622622	31246.61984	4.282534155
328.0839895	145.3568331	0.020833333	507086.6142	2.204622622	34718.46649	4.514187363
360.8923885	152.4515327	0.020833333	557795.2756	2.204622622	38190.31313	4.734519648
393.7007874	159.2304327	0.020833333	608503.937	2.204622622	41662.15978	4.945044495
426.5091864	165.732289	0.020833333	659212.5984	2.204622622	45134.00643	5.146965495
459.3175853	171.9885243	0.020833333	709921.2598	2.204622622	48605.85308	5.341258519
492.1259843	178.0250358	0.020833333	760629.9213	2.204622622	52077.69973	5.528727821
524.9343832	183.8634664	0.020833333	811338.5827	2.204622622	55549.54638	5.710045541
557.7427822	189.5221232	0.020833333	862047.2441	2.204622622	59021.39303	5.885780223
590.5511811	195.0166559	0.020833333	912755.9055	2.204622622	62493.23967	6.056417884
623.3595801	200.3605674	0.020833333	963464.5669	2.204622622	65965.08632	6.222377869
656.167979	205.5656047	0.020833333	1014173.228	2.204622622	69436.93297	6.384024992
688.976378	210.6420631	0.020833333	1064881.89	2.204622622	72908.77962	6.541678978
721.7847769	215.5990251	0.020833333	1115590.551	2.204622622	76380.62627	6.695621898
754.5931759	220.444552	0.020833333	1166299.213	2.204622622	79852.47292	6.846104101
787.4015748	225.1858375	0.020833333	1217007.874	2.204622622	83324.31957	6.993348991
820.2099738	229.829333	0.020833333	1267716.535	2.204622622	86796.16621	7.137556926

Table 10: Theoretical Calculations of Durability of PVC

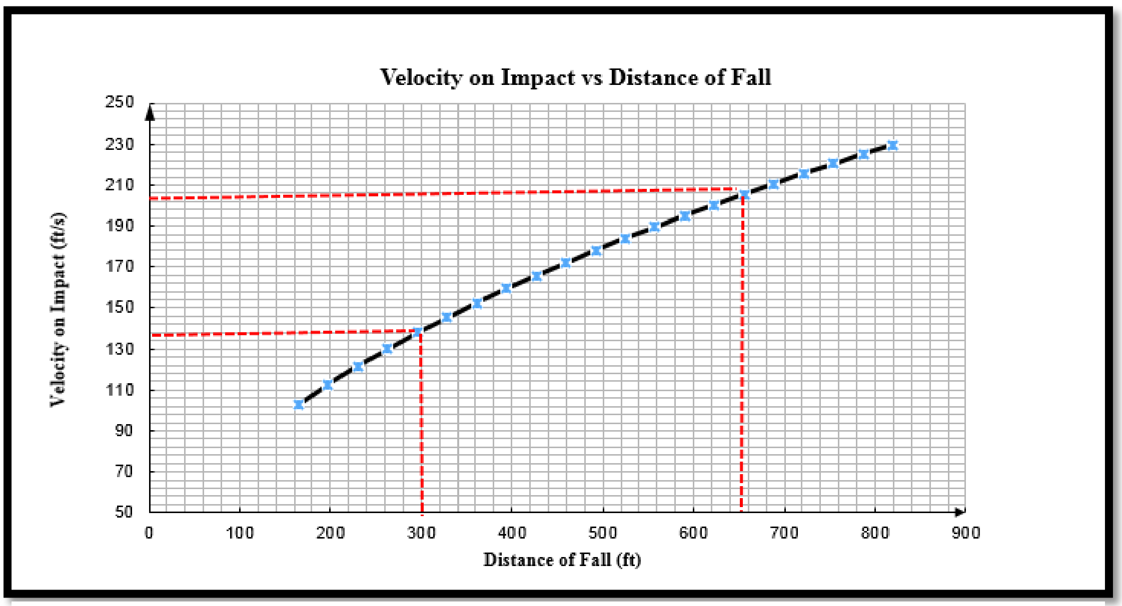

Figure 19: Velocity on Impact Vs Distance of Fall

Evaluation of Results

The graph demonstrates a near linear relationship between the velocity on impact and the distance of fall. The area bounded by the red lines is our distance of focus, which ranges from 328 to 658 feet. The solution for the velocity on impact of a falling object will only consider the beginning and ending energies; intermediate processes will not be evaluated, using the assumption that the law of conversation of energy guarantees that the final energy of the system is the same as the intital energy.

For this calculation, we will also assume that air resistance is negligible.

As a precaution, we will require a PVC enclosue which would withinstand a minimum of 210 feet/second worth of impact.

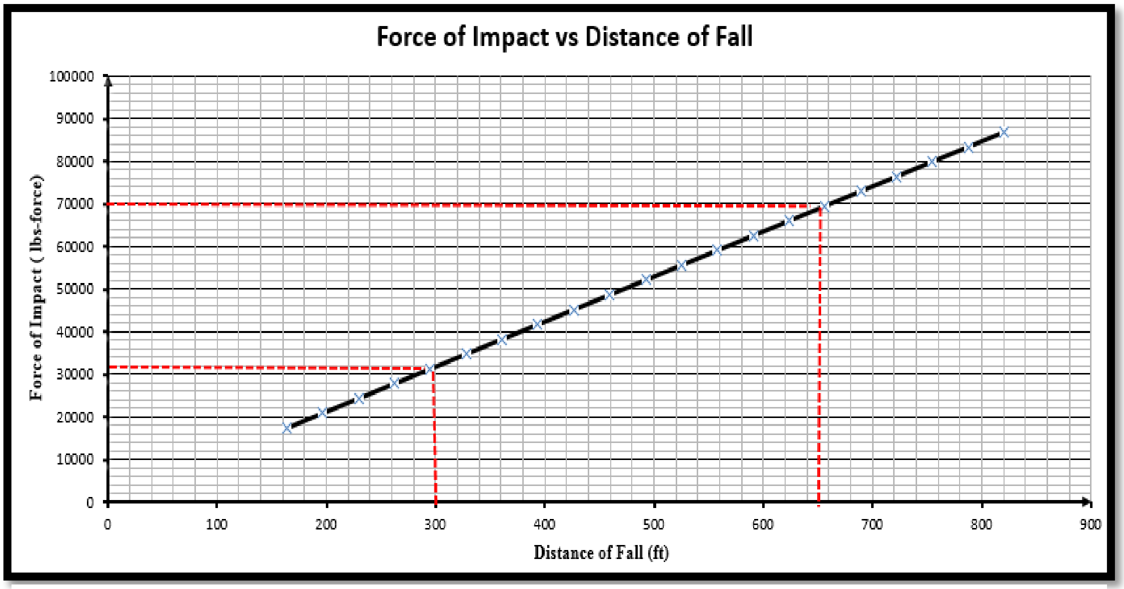

Figure 20: Force of Impact Vs Distance of Fall

The graph demonstrates a linear relationship between the force of impact and the distance of fall. The area bounded by the red lines is our distance of focus ranges from 328 to 658 feet. Thus, as a precaution, we will require a PVC enclosue which would withstand a minimum of 700K lbs-force.

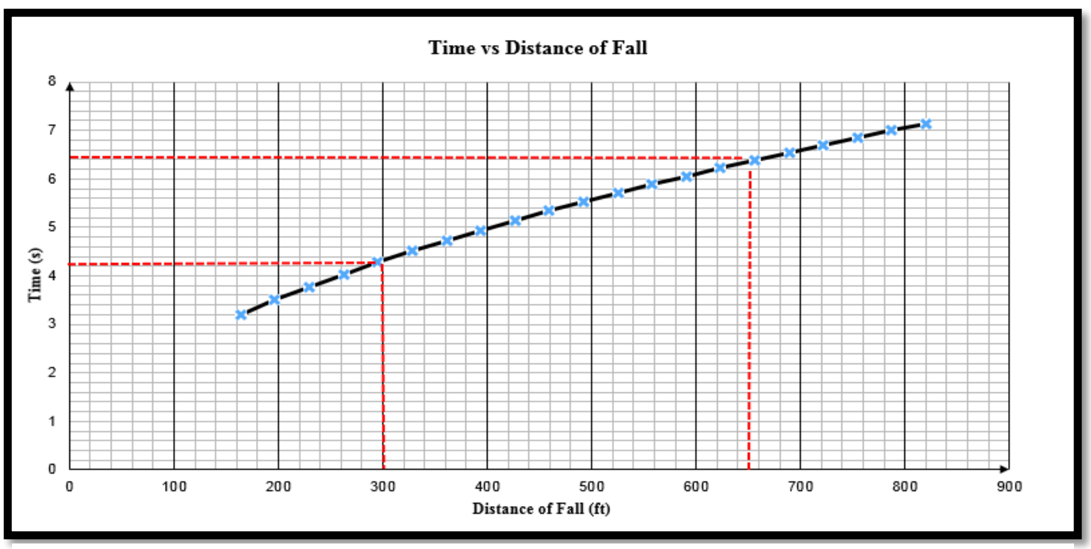

Figure 21: Graph of Time Vs Distance of Fall

The graphs demonstrate a near linear relationship between time and the distance of fall. The area bounded by the red lines is our distance of focus ranges from 328 to 658 feet. Thus, it is expected that the enclosure would only take approxiamately 6 seconds before reaching impact.

Conclusion

It is crucial that we understand the amount of impact which the Skyno unit would undergo upon falling. This allows us to devise and plan for suitable and sufficient cushioning, to protect the payload and enhance its durability.

Appendix K - Budget List

Item	Price (£)	Quantity
Totex Weather Balloon	139.99	1
Helium 4.6 L50 200B	62.84	1
Rental charge per cylinder per month	2.95	1
Picavet	42.15	1
FH-25HD 550tv Line Day/Night FPV Camera	89.95	1
Tau 2 with lens	1392.00	1
FPV 5.8 GHz TX/RX 200mw Combo	79.99	1
Circular Wireless 5.8GHz Skew Planar FPV Antenna	29.95	1
TRACER Lithium Polymer Battery	84.95	1
Total Costs	**1924.77**	

Table 11: Budget List