Literature Review

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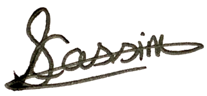

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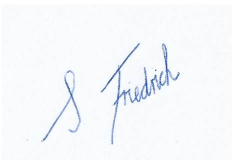

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Problem Statement and Proposed Solution

1.1 Problem Statement

Kyle, who monitors eagles in the Kruger National Park(KNP), needs a way to remotely adjust his camera and access its status and contents, because he has to wait up to 8 months, for data retrieval, to confirm that the equipment has been working correctly. [1]

1.2 Proposed Solution

In order to meet the requirements of our problem statement, we propose a system with the following 4 sub-modules:

1. Power Management,
2. Communications (transmissions),
3. Camera System (rotation and angle adjustment), and
4. Mounting, physical infrastructure and interfacing

The system will allow the camera trap's position to be adjusted where necessary and wireless communications will be used to transmit images so that they can be accessed without physically retrieving the SD card currently used. In order to support these additional parts of the system, a power management sub-module is required - this would include the solar power currently used and configuring it for the additions to the system. Mounting and physical infrastructure is necessary to ensure that the system is secure and stable while interfacing is important to ensure the sub-modules are able to communicate and are compatible.

Chapter 2

Literature Review

This Literature Review explores literature relevant to the problem statement described in section 1.1 above. Focus is placed on camera traps, data management, wireless communication and existing solutions. Each of these topics are considered generally as well as in terms of the specified problem statement.

2.1 Background Information

2.1.1 FitzPatrick Institute Martial Eagle Conservation Project

The FitzPatrick Institute of African Ornithology at UCT initiated a Martial Eagle conservation project with the aim of understanding the factors responsible for the diminishing population in the Kruger National Park (KNP). This was in response to the reported 54% population decrease in large protected areas (including the KNP) between the Southern African Bird Atlas Project (SABAP) 1 and SABAP2. It is suspected that low adult survival and poor breeding productivity are responsible for this. [2, 3]

Kyle Walker, a researcher involved in this project uses camera traps to monitor Martial Eagle nests south of Shingwedzi. [4] He expressed concerns about being unable to confirm whether his equipment was working or aimed correctly until data retrieval approximately 8-9 months after installing a camera trap in a tree. [1] This suggests that there is a need to retrieve data more often and that the ability to make small adjustments to the camera trap remotely if necessary would be useful. It must also be kept in mind that Kyle wishes for any mechanical movement to be as minimal as possible to avoid disturbing the birds. [1].

2.2 Camera Traps

This section reviews the relevant literature about wildlife observation using photographic and video records. It begins with a brief history of camera trapping and then proceeds to explore current, commercial camera traps, their features and limitations, as well as ways of overcoming these shortcomings.

2.2.1 A Brief History of Camera-Trapping Animals

Soon after the invention of the camera in the 19th century, one of the first photographs of wildlife was produced in 1863 by the German explorer, Professor G. Fritsch, in South Africa [5]. Another famous example of early animal photography is that of the quagga photographed at the London Zoo in the 1870s, after quaggas, as a species, had already gone extinct in the wild [6].

In the 1890s, George Shiras, who is credited by many as being the 'father of wildlife photography' [7], devised a system of getting animals to photograph themselves. He used ropes, strings, and a complex system of wires to remotely trigger a flash and a camera when the strings were disturbed. He often used bait, which he attached to the strings, to entice animals into triggering the trap. The flash was generated via a bright explosion using magnesium powder. Using this innovative method, which he dubbed 'flashlight trapping', Shiras' wildlife photographs were able to win a gold medal at the World Exhibition in Paris in 1900. His photographs were also published in the National Geographic Magazine [5].

Fifteen years after Fritsch's milestone accomplishment, with the improvement of cameras' shutter speeds, Eadweard James Muybridge was able to line up a series of 12 cameras in 1878 [8]. He used tripwires to trigger the cameras' shutters as a horse moved past, capturing a sequence of photos illustrating the different positions of a horse's legs as it walks, trots and gallops. This led to the development of motion pictures and a better understanding of how animals move.

Not only were early cameras slow, but they were also large and bulky setups. The advancement of technology, however, saw cameras becoming smaller and more portable, resulting in the 'Bird-land Camera'. This camera, by design, was meant for photography of nature, featuring a green leather exterior 'to fit with the naturalist photographers' [9].

While flashlight trapping saw extended usage in the years following its discovery, famous ornithologist, Frank M. Chapman, made the first clear-cut attempt at recording which animals are present in an area and deducing their behaviour using remote photography in 1927 [5]. This method of analysing animal behaviour was the subject of much interest and research, and still fascinates ecologists and zoologists today. Notably, Oliver Pearson, an American Professor of Zoology, designed a flashlight trap in 1959, which by then had discarded magnesium powder explosions for flash tubes [10]. His setup featured a clock, a ruler, and a thermometer in the field of view of the camera. He also explored alternative triggering mechanisms for his traps, such as using a beam of red light, which once interrupted, captured a photo, and a pressure pad which closed an electrical circuit, triggering a photo, when stepped upon by a small animal [5]. Many similar camera trap systems using 6V batteries (often taken from cars or motorcycles) and movie cameras were devised in the 1960s to increase the portability of these systems and to allow for a series of pictures to be taken.

Further technological developments in the 1970s saw the deployment of 35-mm and Super-8 film cameras, which could be attached to electronic timers, allowing for photos to be taken at regular intervals [5]. These cameras would then be left in the field until their film ran out, and had to be replaced.

The 1990s and 2000s saw rigorous use of camera traps as a means of documenting the population size and activity of more elusive animals such as tigers, jaguars, leopards, coyotes, ocelots, and bobcats [5]. The uses of camera traps were, however, not limited to these investigations; nest and seed predation, feeding ecology, habitat analysis, seed dispersal, and nesting behaviour were also common themes of camera trap research. Camera traps have also been especially useful for monitoring and capturing photos of endangered species of animals, for example, the Asian tapir [11].

2.2.2 Current Camera Trap Landscape

Modern camera traps are much smaller and more powerful than their predecessors, largely due to innovations in the semiconductor industry, such as the Complementary Metal-Oxide Semiconductors (CMOS) technology [12], which is used in modern Integrated Circuits (ICs). Newer battery technologies have also extended the effective field life of camera traps.

Flash

There are four different types of flash available for modern camera traps [13]: Strobe Flash, White Light-Emitting Diode (LED) Flash, Infrared Flash, and Black Flash. Each kind of flash has its benefits and limitations. Strobe flash is able to shoot both pictures and videos in colour during the day, but is only able to shoot colour pictures, not videos, during the night. It achieves colour photography in the dark by triggering a bright, visible flash, potentially alerting or disturbing animals [14]. Strobe flash is also the most battery-intensive flash type available on the market, requiring the longest time for the flash to recover before it can shoot again.

The white LED flash is able to capture colour photos and videos both during the day and during the night. Like the strobe flash, it uses a bright, visible light to capture colour in the dark, but contrary to strobe flash, white LED flash uses minimal battery power [13].

Infrared flashes and black flashes are similar in many regards. Both are able to take colour photos and videos during the day, but only black and white photos and videos during the night. Their power usage is considerably less than that of the strobe flash. Both types of flashes are completely invisible to animals, however, a red glow may be noticed when looking directly at the emitter of an infrared flash apparatus. Consequently, Henrich et al. noted in a 2020 study about deer in Southern Germany, that the animals are more likely to react to infrared flash than to black flash [15]. Infrared flash and white LED flash are also susceptible to motion blur at night [13]. Because strobe flash and white LED flash use bright, visible light, their image quality is much superior to that of black flash and infrared flash [14].

Triggering System

Most modern camera traps use a Passive Infra-Red (PIR) triggering system to capture images of wildlife [14]. PIR systems detect animals by registering a difference between the ambient temperature of the background and the rapid change in heat of an animal's body [16]. This, however, presents itself with several challenges to detection.

Hotter climates, such as the South African climate, have a higher background temperature. This makes distinguishing an animal's body heat from scenery more difficult [14]. To minimize the chance of false triggering, it is thus recommended to trim loose vegetation that could swing in the wind. A 2015 paper by Welbourne et al. outlines the use of an infrared filter to limit the wavelengths reaching the sensory element of the PIR system [17]. This reduces (but does not completely eliminate) the likelihood of false triggering by limiting the temperature threshold of the sensor system to within the range of an animal's body temperature[16].

False triggering poses a problem because is associated with greater battery drainage of cameras, slowing down data processing and also wasting space on the camera's Secure Digital (SD) card. Additionally, smaller animals, which radiate less heat, and animals which are further away, make detection via sensors difficult. Consequently, most PIR systems have an effective range of 15-25m [13].

Trigger Delay and Recovery Time

To preserve battery life between photos, most camera traps enter a 'deep-sleep' mode while awaiting instructions from the detection sensory system [14]. Naturally, this means that a delay, known as the trigger delay, exists between when the detection system is triggered and when the camera is ready to shoot pictures. Trigger delay varies by camera type and is usually within the range of 0.2-0.5s for photographs and 0.4-1.7s for videos. Depending on the trigger delay of a camera, an animal passing by the camera's field of view may already be leaving, or have entirely left, the camera's frame by the time the photo is taken. This is known as a 'missed image'.

Some camera models allow for adjustable trigger delays, which can be useful when trying to have a subject captured in the middle of the camera's frame. Similar to flashes, cameras also have a recovery time, which dictates how soon after taking a photo or video a camera is ready to take another one. For still photographs, the recovery time usually lies in the range between 0.5-3.4s, while videos usually have a recovery time of 0.7-5s [14]. Most modern cameras are able to shoot many photos in quick succession, in what is known as 'burst mode', however, recovery time still applies after a burst of pictures is taken.

Battery

Modern camera traps have several options to choose from when selecting a power source. Choosing the right battery is of critical importance, as low battery power can result in poor detection from the PIR circuit, dull flash brightness, and inconsistent performance from the camera when capturing photos or videos [18]. The average trail camera runs off either 6V or 12V. To achieve this voltage, one can use lithium batteries, alkaline batteries, or rechargeable Nickel-Metal Hybrid (NiMH) batteries [13]. Lithium batteries, when new, have around 1.85V. They function well in extreme weather, in temperatures of -40°C to 60°C [19], and have a good power output with around 2900mAh of capacity.

Alkaline batteries are generally cheaper than lithium batteries [19] but have a lower voltage of around 1.7V per battery[18]. The capacity of alkaline batteries is usually lower and less reliable than that of lithium batteries, to the extent that lithium batteries can last up to six times longer than alkaline batteries [19]. Alkaline batteries also struggle to perform in temperatures of less than 5°C [18]. NiMH batteries, while more sustainable and environmentally friendly than the alternative options have a lesser voltage of 1.2V per battery, and their performance tends to differ from their pack specifications, sometimes leading to unsatisfactory results [18, 13].

Newer cameras have very low current draw requirements, meaning that lithium and alkaline batteries are able to last up to 10 months in a camera trap (depending on its activity) before they need to be replaced [13]. Some modern camera traps are also compatible with an external 6V or 12V power supply, allowing for rechargeable Sealed Lead Acid (SLA) batteries or solar panels to be connected to the camera trap via a port or jack.

Memory cards

The most common way of storing data from camera traps is through the use of SD, Secure Digital High Capacity (SDHC) and Secure Digital 'Xtra Capacity' (SDXC) cards. All of the aforementioned memory cards have different storage capacities, which dictate a camera's field time, as well as the resolution of the photos and the colour of the images which can be stored on them [20].

SD cards, and their sub-types, have a minimum write speed, known as the speed class, which indicates how fast the data from the camera can be written to the memory card. The speed classes available are Class 2 (C2), C4, C6 and C10. An SD card with a speed class of 4 has a minimum write speed of 4MB/s [21]. Since hundreds of photos are taken by one camera trap, and often in quick succession, it is necessary for the SD card to have a fast speed class rating [22]. For camera traps, it is thus recommended to use a C10 SD card [23, 24].

Camera traps usually create low-resolution images with a small file size since their built-in image sensors are compact. For short and medium-term deployments, which take less than 4 weeks, a low-capacity (4GB) SD card can be used while for long-term deployments, which take more than 4 weeks, a high-capacity SD card (>4GB) should be used [21]. Furthermore, to cater for false triggers and missed images, a high-capacity SD card is preferable.

Wireless Fidelity (WiFi) SD cards have also been implemented in camera traps and these can send images to computers and other electronic devices using WiFi networks. WiFi SD cards might not work with some camera traps as they go into sleep mode immediately after taking a photo, leaving the camera with insufficient time to wirelessly send the photos [21].

2.3 Data Management

2.3.1 Analysis and Processing for Optimisation

Traditional methods of monitoring birds in their protected habitats can be difficult and invasive as they require human presence in the birds' habitats [25, 26]. This has resulted in modern surveillance tools such as video and camera traps increasing in popularity. Motion sensing camera traps specifically are capable of accumulating significantly large amounts of visual information [25]. Not all of this information is required for research and it is therefore important to ensure that the transmitted outputs only contain data that is useful and of interest. Accurate object identification and filtering of uninformative data are thus necessary and data should be analysed and processed before transmission or storage [25]. For example, the system's motion sensor may be falsely triggered resulting in a large number of images in the data set that may not be useful. Image processing would then be used to remove the uninformative images from the data set and identify and extract useful images from a larger data set automatically [25]. This can be achieved by implementing the fast algorithm which can identify useful image data from a larger set [27, 25]. Additionally, for the extraction of desired visual data, convolutional neural networks may be used. This involves using the binary classification of the system where an image either contains the subject of interest or not[25].

Video Synopsis

A camera trap may record video instead of capturing still images thus providing a more dynamic representation of the captured subject's world [28]. However, retrieving the video and processing it to gather information may be bulkier and take a longer time thus requiring more storage space. Additionally, most of the captured footage may not contain any events of interest worth examining [29]. Video synopsis is a tool that optimizes videos to save power, storage and time. It can be used to generate a shorter version of the original video containing only relevant data thus reducing spatio-temporal redundancy. This is achieved by condensing the video's activity and showing events that occurred at different times either closer together or simultaneously [28]. This is useful specifically in the context of monitoring birds using a camera trap because the user is able to store and/or transmit shorter versions of the surveillance, thus reducing the time required to manually collect relevant data. There are multiple approaches to video synopsis and it is important to ensure that the approach chosen maintains the integrity of the data collection system.

2.3.2 System Configuration

A remote system must be robust as it cannot be continuously monitored to ensure it is operational [1].In order to improve overall system efficacy and resilience, a master/slave(s) approach may be adopted. In a study of the free movement and migration of mammals by Matuska et al [30], an intelligent remotely operating camera system was used to recognise the migration corridors of the animals. The system consisted of a master device and multiple slave devices. The master device was responsible for receiving and storing information collected by slave devices as well as information on their statuses. The slave devices were used to detect and track the subjects, and collect data [30]. The configuration of this system could be transferable to a camera trap system, where the master device is responsible for transmission so that additional hardware does not need to be added to existing camera traps. This also reduces the amount of equipment required near nests thus minimizing any disturbance to the birds.

An eagle-watching camera system may experience difficulties, such as signal loss, whilst collecting data without human intervention [26]. The master-slave(s) configuration may allow for a more robust system by breaking down the system into several, smaller subsystems. This way, the risk of the system being in the way, being too heavy or experiencing detrimental damage (to the entire system) can be reduced. The master device may be at another suitable location and contain the rest of the system. An example of a camera in the market is the Bushnell Cellucore 20 solar trail camera which has a control panel, an antenna and a solar panel [31, 32]. Adopting such a configuration would result in the camera being lighter and easily mountable without, for instance, the solar panel and the control panel. At a convenient nearby location, through wiring, a master device can contain a larger and more conveniently placed solar panel and control panel. This way, a user interacts with the system but not directly with the camera.

2.4 Wireless Communication

As communication approximately 50m from a camera trap is desired [1], focus has been placed on low range wireless communication implementations.

2.4.1 ZigBee

The ZigBee protocol was used for communication in the WISN described in section 2.5 [33] and supports a bandwidth of 250 kbps for up to 125m using 802.14.4 radio, operating in the 2.4 GHz band [34]. It is designed to be a low-power, low-cost and simple network standard [35]. ZigBee can be configured in Line of Sight (LOS) and Non-Line of Sight (NLOS) modes. The two modes perform differently with LOS having a stronger Recieved Signal Strength Indicator as well as lower packet loss and error rates[36] .

2.4.2 Bluetooth Low Energy (BLE)

BLE was developed as a low-power model of Bluetooth for Internet of Things (IoT) applications. It has a range of approximately 150m in an open field making it useful for low-range, low-power applications[37].BLE also allows users to set up faster connections as it has a link set up time minimized to 3ms[38] Further, it is considered to have good data throughput and ‘small and simple software stack, applicable for 8-bit microcontrollers’ for wireless sensing applications[39].

2.4.3 Comparison of ZigBee and BLE

ZigBee and Bluetooth Low Energy (BLE) are two low-power wireless communication solutions [40]. Lee et al found that ZigBee had a longer transmission time than BLE due to a much smaller data rate. BLE is also found to have a much better data encoding efficiency than ZigBee for smaller data sizes. However, as the data size increases, the efficiency difference is quite small[40]. Thus for the transmission of high-resolution images, the data encoding efficiency is unlikely to be drastically different. However, ZigBee will take much longer to transmit an image.

2.5 Existing Solutions

2.5.1 Wireless Image Sensor Nodes (WISN)

In a 2014 paper, Zhang et al. developed a wildlife monitoring system based on WISNs. The system can be broken down into 2 main sub-systems - monitoring and transmission - which could each be broken down further into hardware and software sub-modules. The image sensor nodes make up the monitoring sub-system and are responsible for capturing data in the form of images while the sink node is connected between the image sensor nodes and the access network thus making up the transmission sub-system. [33]

Their full system includes ‘a wireless infrared image sensor network, a base station and a wildlife monitoring center’ illustrated in figure 2.1 [33]

Monitoring Sub-System

The image sensor nodes include an image acquisition sub-module, an image processing module and a ZigBee transceiver among other modules. The image acquisition sub-module contains pyroelectric infrared sensors which are used to trigger image capturing. Based on the available lighting, the camera will either capture black and white or fully coloured images. The camera can also be moved by adjusting the rotation angles of servo motors attached to the camera as well as the camera lens itself. Local image processing is completed using the Amtel AT91SAM7X512 processor and transmission to the sink node is completed using the TI CC2520 ZigBee transceiver. [33] This system was developed to monitor Red Deer (cervus elaphus) and is thus not ideal for bird monitoring but many of these concepts are transferable.

Transmission Sub-System

The sink node utilizes a PXA270 processor, the same ZigBee transceiver as the monitoring sub-system, memory and a 3G communication sub-module among several other interfaces. Both SDRAM and Flash memory are used for the memory sub-module. The SIMCom SIM5218 communicates with the processor via UART and is used as the 3G sub-module. The sink node is only activated once it receives a request to join the network. It is then initialized and will receive images via the ZigBee protocol and transmit them via 3G. [33]

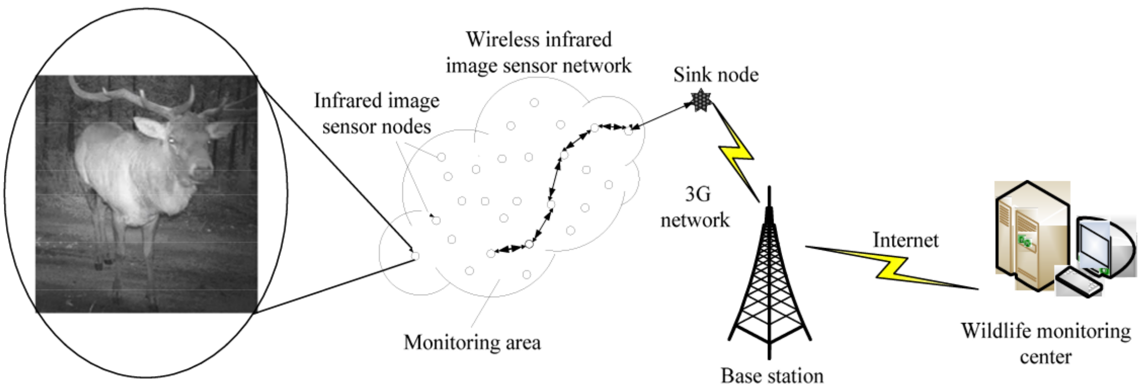

Figure 2.1: Wildlife Monitoring System based on WISN

2.5.2 Important System Features

Movable Cameras

The developed system includes rotatable image sensor nodes allowing for camera angle correction. Three pyroelectric infrared sensors with sensing angles of 120 are used to detect motion and trigger camera adjustment - the 2 servo motors to rotate the camera and the camera lens is adjusted. This allows for the camera to capture useful images based on motion. [33] While the motion-activation may not be directly applicable to the problem statement, the camera adjustment techniques are transferable and can be applied to this design.

Transmission Capability

This system has 2 levels of transmission - between the monitoring system and the sink node and between the sink node and a larger network [33]. This allows for easy isolation of errors and for better power management.

2.6 Chapter Summary

This literature review is in response to the problem of remotely operating a camera trap monitoring eagles from their nests in a tree. In its contents, it has presented the history and development of camera traps through the last two centuries, important technical features and requirements of a camera trap system, as well as existing solutions that may address the problem and optimization suggestions.

It has become clear that research on the use of camera trapping for birds and bird nests is not very extensive, especially for birds whose nests lie above the ground. However, the research analysed is in agreement that, the size of the bird and its distance from the camera are some of the most fundamental things to consider. Issues which need to be addressed by the solution at hand include ensuring minimal disturbance to wildlife, minimizing the occurrence of false triggering and missed images, battery preservation, storage, and transmission and processing of data. For the most part, existing camera trapping systems were found to address similar problems or aspects of the problem, and therefore have the potential to be transferable. Existing solutions included a wildlife monitoring system based on wireless image sensor nodes with a monitoring and transmission subsystem. Proposals from the relevant literature included using wireless communication technologies, exploring image and video processing tools and breaking the system up into several subsystems.

In conclusion, while there is a clear growth in the usage of camera traps for mammals, research on the monitoring of birds and nests above the ground is lagging behind. Consequently, this project focuses specifically on using camera traps to observe birds in their nests.

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