EEE4113F Draft Literature Review

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Chapter 1

Literature Review

1.1 Starlings and the need to monitor nest environments

1.1.1 Current monitoring of Red-Winged starlings

Verstraeten et al. [1] explain that the monitoring of birds has widespread potential in numerous applications in ecology, climatology, and avian related zoonosis/infections such as avian influenza. Researchers from the Fitzpatrick Institute of Ornothology indicated a desire for a remote-monitoring solution for Red-Winged starling nests [2]. Their existing solution is a GoPro camera on a pole, which they hold up to the nest to try and view what is happening [2]. This allows only limited amounts of data to be gathered, and disturbs the birds [2].

1.1.2 Starlings and nesting

According to Ricklefs [3], a starling bird can reach full body growth in approximately 20 days and an adult starling can reach a body mass of 79 grams. [3] further details that a newly hatched starling chick can weigh 5.27 grams and can be one of up to 18 chicks in brood in the starling nest.

1.2 An overview of existing full camera trap systems

Swann et al. [4] argue that while choosing from a selection of camera traps designed for generalised use cases may be complex, it becomes essential to refine a module designed for nest ecology researchers. Meek et al. [5], emphasise the key elements such as cost effectiveness, speed, space and weight saving, usability, and versatility as being critical in developing an efficient wildlife surveillance system.

Recent studies highlight the ongoing efforts to improve camera trap systems in wildlife research by addressing issues of detection reliability, data cataloguing, and remote communication capabilities, while also revealing challenges in power consumption, weight, and cost. Nazir, Sajid, et al. [6] introduced the "WiseEye" camera trap system, which aimed to address frustrations of existing camera systems. The "WiseEye" system, consisting of a Raspberry Pi and passive infrared sensors, promised and showed an improvement in detection reliability, reduced data cataloguing time, and remote communication capabilities. With this solution came many drawbacks such as lower power efficiency, weight, and cost. This indicates potential areas that can be simplified and optimised to suit nest ecology research. Rico-Guevara et al. [7] contributed by confirming the importance of having a PIR sensor in their study that involved capturing pictures of hummingbirds. They also had issues when it came to power consumption and weight. This is a recurring issue among existing designs. Green, Sian, et al. [8]

explored the integration of artificial intelligence with existing camera trap solutions, in a bid to offer advancements in data processing and analysis. This brought upon its own issues such as increased power consumption and greater computational requirements that would only be fixed if the whole system is redesigned.

Additionally, Rovero et al. [9] emphasises the importance of establishing a selection criterion when choosing amongst off-the-shelf products, especially in niche environments like nesting areas.

Aguiar-Silva, Francisca Helena, et al. [10] agreed on the use of infrared sensors because of the prevalence of nocturnal predators that attack nesting areas of birds. This will make it easier to analyse activity regardless of night or day in confined areas.

In a study regarding nest predation, Ribeiro-Silva et al. [11] again stress the importance of infrared cameras but warn against positioning them too far away from the nest to reduce overexposure of the captured footage.

Wireless data transmission and automation emerge as crucial requirements in modern camera trap modules, according to Glover-Kapfer et al. [12]. However, they make note of the fact that availability of good camera traps, i.e., those that are relevant to the researchers' requirements, is often dictated by the novelty task at hand, which may limit the available options for studies in nest ecology.

1.2.1 Challenges and limitations of consumer camera traps

Addressing operational challenges and efficiency issues in nest monitoring systems is important when designing effective wildlife research modules, as indicated by Ribeiro-Silva et al. [11], identify various shortcomings in existing solutions and proposed strategies for improvement. In the pursuit of effective nest monitoring, [11] found that problems like insufficient storage, wind displacement, weather damage, and false detection of animals outside the intended field of view led to poor efficiency, loss of data, and missed predation lists. Suggested improvements from [11] include camera positioning, increased storage, regular inspection, and the use of more than one camera to progressively monitor activity around the nest.

[13] suggest that existing camera trap modules may not meet the standards that are expected for scientific research and conservation. [13] stresses the necessity of laying groundwork to establish hardware standards tailored to each study, challenging the feasibility of adopting off-the-shelf modules for diverse researching tasks.

A Bushnell TrophyCam, which captures both videos and photos, was found to provide intuitive data for distinguishing between different birds within the same species through analysing their behaviour from short video intervals. Challenges experienced involved low detection efficiencies with motion sensors and a need for managing the video lengths to optimise data storage [11].

1.3 Data transmission techniques

1.3.1 Comparison of wired and wireless data transmission

Despite the improvements of wireless communication capabilities, wired communications have traditionally served as the industrty standard. Huynh's study on general communication protocols [14] sheds light on several key advantages of wired data transmission. These include implementation of parallel data transfer techniques, with the speed can be adjusted by the number of parallel cables, provided the transfer rate per cable is maintained and the cables are shieled to minimise cross talk. [14] also made note of differential lines being utilised instead of single-ended lines, to improve data speeds, lower the power consumption and reduce electromagnetic interference, all pertinent to the scope of the design.

Gula et al. suggest that wired solutions may introduce problems such as cable management and animal interference. [15] details how different coaxial cable thicknesses are required to transmit different data types over a set length without any additional amplification, resulting in a cluster of cables running between subsystems. [15] also noted concerns that animals, such as rats, end up chewing the cables over time.

Given the challenges associated with wired communications in wildlife research, wireless data transmission becomes a promising alternative. Adsumilli, C et al. mention that 'error resilience and error concealment were the most important aspects of current research for successful realization of transmission and reception of image/video signals over bandwidth limited fading wireless networks/channels.' [16].

Li et al. [17] suggest that implementing a wireless communication system will present a more cost-effective solution for wildlife research. [17] further stipulares that deploying a wireless system will reduce the overhead that comes with maintenance when the connections get damaged.

[16] H.263 and MPEG-4 encoding standards, which were implemented to achieve error control for both reception and transmission of video in error prone environments [16].

In exploring alternative wireless connectivity modules for low power IoT devices, Peng, Y. et al. [18] put forward a solution that is suitable for long-range transmission of low-rate data, which offers a simplification of camera modules in wildlife research. The study goes into the wireless device designed for batteryless IoT devices (passive devices), that are capable of transmitting data over long distance. While this is unsuitable for video or image transmission, the device will allow for the user to wirelessly obtain logs on the status of the module even when power has run out. [18] reported a maximum packet detection range of 50 m, making it a possible solution for smaller data transmission needs.

Conversations with the researchers for the project at hand [2] WiFi-based communication may be hampered by a lack WiFi connectivity at many of the red-winged starling nesting sites.

1.4 Computing hardware and integration with the Internet of Things (IOT)

1.4.1 Single board computers and micrcontroller hadware

Single-board microcomputers can be a valuable tool for biological research. Jolles argues that '[T]he Raspberry Pi [is] a great reserach tool that can be used for almost anything. This can range from ... video recording of laboratory experiments, to long term field measurement stations' [19]. The wide versatility of a device like the Raspberry Pi makes it ideal for implementation of customisable video monitoring solutions. Jolles [19] also argues that the small footprint of the Rasbperry Pi aids in its use in research, and versatile options for the provision of power allow it to be used with minimal human intervention over long time periods. These benefits align strongly with the needs of the project at hand, further emphasizing the Raspberry Pi as a viable platform around which to base the project.

Data storage and retrieval has been identified as a key limitation in the application of camera traps to monitor Red-Winged starlings [2]. Prinz et al. [20] implement a project for video surveillance of Acorn Woodpecker nests. They justify the Raspberry Pi as useful resource owing to its small size and variety of storage and connectivity options. The particular project uses a WiFi connection to upload footage to cloud storage on Google Drive. They further identify that the onboard SD card has sufficient storage for around 3 days worth of footage, but also identify the strength of the Raspberry Pi in its ability to leverage 3G/4G connectivity or external flash drives and hard drives as alternative means of data storage. The variety of footage collection and/or storage options make it likely that a suitable option can be found in the case of Red-Winged starlings.

[19] acknowledges the existance of other microcomputer systems, argues that the use of these systems is hampered by lack of hardware and software maintanence, alongside generally poorer user support compared to the widespread Raspberry Pi.

Microcontrollers, including options from ST Microelectronics, Espressif, and Atmel offer an alternative to full microcomputers. Camacho et al. [21] discuss a custom design based on the ATMEGA2650 microcontroller. They use a customised circuit design to allow for advanced power management, with the goal of limiting power draw. [21] further describe difficulties with using commonly available prototyping board, which are not necessarily as capable of achieving power draw requirements as custom circuit designs. Cardoso et al. [22] implement a remote visual surveillance based on an ESP32 microcontroller, demonstrating a successful microcontroller-based implementation under slightly different circumstances to [21]. [19] also identifies that microcontrollers may have even less stringent power requirements than the Raspberry Pi and argues that simple, repetitive tasks are often better suited to microcontrollers. Microcontroller based solutions may offer more customisability and lower costs compared to microcomputer solutions such as the Raspberry Pi.

[19] also identifies that microcontrollers and microcomputers can be used in tandem in some instaces. This would allow the benefits of both systems to be realised, such as allowing for exceptionally low power draw the majority of the time, but allowing for the advanced connectivity options of the Raspberry Pi when required.

Both microcontroller and single-board microcomputers have varying price, typically depending on processing power and available peripherals. Local market prices may make higher-end devices too costly to be viable, and microcontrollers are generally significantly cheaper than microcomputers.

1.4.2 Software for computing hardware

Raspberry Pi computers allow for 'user-friendly programming capabilities' [19], with an operating system based on debian linux, which allows for python programming [20]. This allow for easy control of the Raspberry Pi's GPIO pins. [21] note their appreciation of the ATMEGA2650's integration with Arduino. ESP32 system can also be coded using the Arduino framework, and options from ST Microelectonics are typically coded in C. While some embedded software frameworks may be easiest to use than others, most available options should not substantially hamper the development of the system.

1.5 Sensing hardware

1.5.1 Motion detection

Meek and Pittet [5] identify that 'Motion detection is of prime importance for any camera trap to be effective'. Importantly, Rovero et al. [9] discuss that the camera field of view does not correspond directly to the detection zone. Motion detection is often a separate process from video or image recording, and must be thoroughly considered to make for a viable solution.

Meek and Pittet [5] identify that most commercial camera traps use passive infrared (PIR) sensors to detection motion of wildlife, but are prone to false detections, resulting in images that don't feature any wildlife. The sensitivity of a PIR motion detector 'depends on many factors, including the distance of the moving target, the temperature differential, the size of the animal, its speed and background light.' Rovero et al. [9] add to this by identifying that PIR sensors can be triggered by pockets of hot air or vegetation. Meek et al. [23] support a similar conclustion, indicating that 'Where the temperature differential between the background and target is low, some sensors may be incapable of detecting target animals right in front of the camera'. Yun [24] explains that they work based on the principle of pyroelectricity, where certain materials generate a voltage when exposed to changes in temperature. [25] details that PIR sensors have found extensive use across diverse fields, particularly in the creation of intelligent settings like healthcare facilities, smart energy systems, and security setups. The prevalence of PIR based motion detection seems to indicate that it is a workable and useful solution, but evidence shows that there are also difficulties associated with the technology.

Rico-Guevara and Mickley [7] chose to use PIR motion sensors because they 'were cheap and easy to deploy, and successfully detected hummingbirds.' Their study found that detection of even the smallest species of hummingbirds was adequate for their application. They chose to combat the issue of false detections by intentionally positioning the sensors away from objects that could trigger unwanted detections, and mitigated the consequently limited scope of an individual sensors by triggering from multiple differently positioned sensors. A separate standalone trigger was also developed which included an adjustable sensistivity, allowing 'fine tuning by optimizing the trade-off between increased sensitivity and false positives' [7].

Welbourne et al [26] identify that the functioning of PIR sensors is often misunderstood, leading to 'flawed inferences or expecatations of camera performance.' A thourough understanding of PIR sensors would help in the development of a robust and well-functioning solution.

Rovero et al. [9] discuss that older comercial camera traps from the 1980s were triggered by a break in an infrared beam. However, newer models come in 'self-contained package including sensors and camera.' Hobbs et al. propose a solution for 'amphibians, reptiles, small mammals, and large invertebrates' [27] using similar technology. However, the solution at hand appears to be too large to viably be integrated into a bird nest, and the system requires the animals to walk over a threshold near the beam, which makes it difficult to apply to birds which fly.

Prinz et al. [20] use an alternative technique which detects changes in the pixels from the camera output. This was achieved using the open-source program motion-MMAL. This alternative technique minimises the hardware requirements of the system.

According to Amusa [25], there are three technologies are used in practice for motion detection; they are Passive InfraRed (PIR), ultrasonic and audio sensors. Ultrasonic and audio sensors do not appear to be widespread and are thus not thouroughly considered in this investigation.

1.6 Choices of camera

[19] notes that the Raspberry Pi Foundation offers two cameras for the Raspberry Pi - the v2 and HQ cameras, both of which connect to the Raspberry Pi via it's Camera Serial Interface. Both cameras deliver the same video performance of 1080p 30fps, though the HQ camera is capable of higher-resolution still image photography, at 4056 × 3040 pixels, as opposed to 3280 × 2464 pixels [19]. Additionally, an version of the v2 board for infrared photography is available, and the HQ board can be used for infrared photography by manually removing it's infrared filter. [19]. Senthilkumar et al. [28] discuss the use of a similar Raspberry Pi NOIR camera. This is likely the first version of infrared enabled v2 board discussed by [19]. [28] that the board '[I]s able to deliver clear 5MP resolution image, or 1080p HD video recording at 30fps.' [28], and further discuss that the sensor's lack of infrared filter makes it ideal for infrared or low light conditions. [20] sites [28] to justify the use of the same camera module in a case of bird nest-monitoring. Camera modules from the Raspberry Pi Foundation appear as enticing options for monitoring of Red-Winged Starling nests, especially if paired with a Raspberry Pi.

Many third party camera modules for the Raspberry Pi exist, with varying capabilities [19]. The local market includes numerous options, alongside many options for use with microcontrollers, at varying price points.

[7] use a mechanical system to trigger a camera unit that would normally be operated by hand. This allowed the researchers to capture high-speed footage in good quality [7]. However, top-range handheld cameras can be prohibitively expensive and may not be as robust as integrated electronic modules.

1.6.1 Pyro-electric (PIR) sensors

Pyroelectric Infrared (PIR) sensors are devices that detect infrared radiation emitted by objects in their field of view.

1.7 Night or low-light visibility

Rovero at al. [9] stipulate that camera trap modules sometimes infrared or white LED flash, to enable camera visibility at night. Flash technology is not generally needed when daylight can provide the necessary visibility for photography.

According to Meek et al. [23], infrared flash tend to be less disruptive to wildlife than incadecent white flash, alongside exhibiting superior power efficiency and faster overall camera trap trigger speeds. However, [23] also explained that infrared flash are 'are often in grey-scale ... or may have a reddish-pink tinge.', whereas white flashes allow for colour images, which is sometimes useful for research. [23] identifies that LED technologies for white flashes can mitigate concerns about power draw and trigger speed. At the time of publication of [23], only one commercial camera trap module used LED flash, but LED technology has since become much more accessibly, making it a much more viable solution than it previously was.

Conversations with the researchers working with Red Winged starlings [2] indicated that infrared flash may be useful for night-time visibility of nests, or for enhanced visibility of some nesting sites that are very sheltered from daylight.

1.8 Power supply

Power plays in integral part, by supplying the entire design with the necessary power to run the device efficiently and adequately. The aim of this research is to determine the best possible approach in order to making the power submodule of the design as optimal as it can be.

1.8.1 Power sources for sensors situated in an impractical setting

There are various power sources that can be used, specifically when it come to remote sensors for lower power consumption applications. Dewan et al. [29] explain that one of the main issues with deploying sensors in remote or impractical environments is the life span of these sensors which is largely dependent on the power supply it is connected to. With this in mind we can look into the various power sources that could be suitable for our design that will follow.

1.8.2 Battery powered supply

Polleneli et al. [30] describe the success of using batteries to power their motherboard for their drone application. They further iterated that their design included generating reliable and stable 3.3 V and 5 V DC voltage from two Panasonic 18650 batteries which managed fast charging. This can be tailored to our design as it has the capabilities of fast charging. Callebaut et al. [31] outlines issues faced with batteries and their lifespans and how to lengthen their life. They further explained the different types of batteries and how the battery type can optimise the battery life. They stated, "Lithium Cobalt Oxide (LCO) and Lithium Polymer (LIPO) batteries are currently the most used rechargeable technologies" [31]. These batteries can be useful and go hand in hand with solar power supply.

1.8.3 Solar powered supply

The popularity and extensive use of solar is explaiend through the statement, "Solar power is used for operating both ground and floating sensors; solar-powered sensors have been deployed in forests, on mountains, in deserts, on ocean surfaces, on islands, and in household and industrial buildings." [29]. This supports the possibility of integrating solar power into the design in order to reduce the number of manual recharges of the battery required. Krejcar further supports the use of solar powered supply for remote sensors and explains that "It is possible to apply the solution from lower voltage (lower sun intensity)" [32], this indicates that it will be able to charge the battery and operate on days that are not extremely sunny.

1.8.4 Power saving operations for sensors situated in an impractical setting

Power consumption is an important aspect to think about when it comes to design and it is very important that power saving operations are put into place in order to make the whole device more efficient. Some of these methods are to be studied and analysed below.

Harikrishnan and Sivagami [33] go into detail talking about how PIR sensors can be used to switch a system on and off depending on weather a sensor is giving a reading or not [5]. This design can be extremely useful in our design as it will switch the device on only when there is motion, hence reducing redundant recordings and saving power. Harsha and Kumar [34] further support this notion and show the justification of the use of a power saving through tests.

1.9 Camera trap deployment in urban settings

Camera traps are valuable tools for wildlife monitoring, but vandalism and theft pose significant challenges, resulting in financial losses and compromised data quality. Despite attempts to mitigate these risks by placing camera traps at greater heights, the impact on detection rates remains understudied. Reference?

Methods:

Meek et al. [35] investigates the effect of camera trap height on predator detection in road-based surveys, monitoring stations were established with cameras positioned at both 0.9 m and 3 m above ground level. Additionally, a pilot trial compared vertical and horizontal camera orientations for medium-sized mammal detection.

Placement of cameras at greater heights significantly reduced detection rates for all species compared to lower placements. False triggers were more common at higher placements, exacerbating data loss. Recommended deployment heights vary widely in existing literature, with limited empirical support and emphasis on the animal size and habitat. Vertical camera placement also showed reduced detection rates, with overhanging limbs causing false triggers.

Although raising camera traps may seem a solution to theft, it compromises data quality and promotes false triggers [35]. Optimal camera trap height is critical for maximizing detection rates, aligning with the size and passage of target animals. Further innovation is needed to address theft while preserving data integrity.

Camera Trap Deployment Strategies:

Roland Kays et al. !!reference?!! discuss the employment of Reconyx RC55 Camera traps known for their resilience in harsh rainforest conditions. Camera traps are strategically placed along trails or near water bodies to maximize animal detections. However, randomized deployments revealed biases in trap rates, with certain species exhibiting preferences for or avoidance of trail-side locations. Furthermore, challenging weather conditions, particularly during the rainy season, impact camera performance, necessitating mitigation strategies such as desiccant packets and preventative maintenance schedules. [2]

Maintenance Challenges and Solutions:

Despite advancements in camera design, maintenance remains a critical aspect of long-term monitoring projects [3] !!reference?!! and data quality !!refence?!!. Common issues include lens blurriness and circuitry failures due to humidity, prompting manufacturers to enhance sealants and coatings. Practices such as drying camera traps with dehumidifiers, inserting silica gel packets, and duct-taping seams minimize moisture infiltration, preventing equipment damage and malfunctions. Regular inspection and servicing of components such as gaskets, contacts, and wires are essential, particularly in humid environments. Additionally, theft poses a potential threat to camera trap networks, underscoring the importance of discrete placement, visible flash mitigation, and security measures such as cable locks and informational signage.Furthermore, periodic inspections during site visits enable lens cleaning, hardware tightening, and battery replacement, ensuring uninterrupted data collection and equipment functionality.

Weather Resistance Strategies:

Utilizing weather-resistant housings, such as the Pelican 1300 case, shields camera equipment from rain, dust, and moisture, prolonging its lifespan and functionality !!reference?!!. Incorporating natural materials and camouflage fabric helps obscure camera traps, minimizing wildlife disturbance and theft risk. Furthermore, the development of zinc rain covers and the application of black glue for waterproofing offer additional layers of protection against environmental elements.

Theft Prevention Measures:

!!refence?!! Implementing security measures such as cable locks, padlocks, and GPS trackers like Apple AirTags deters theft and aids in equipment recovery. Discreet placement and camouflage techniques reduce the visibility of camera traps, minimizing the likelihood of detection and tampering. Additionally, strategic positioning of camera traps at elevated heights and on stable mounts mitigates theft risk while optimizing surveillance coverage.

DIY Article

This article describe DIY camera traps !!refernce?!!, researchers and enthusiasts can construct for wildlife monitoring effectively. By leveraging appropriate equipment, security measures, and maintenance protocols, individuals can capture

Equipment Selection and Components:

The DIY systems, is reinforced in this article!!reference?!!, which highlights the importance of selecting suitable equipment for DIY camera traps. Components such as DSLR cameras, wide-angle lenses, waterproof cases (e.g., Pelican 1300), and motion-detection sensors (e.g., Camtraptions V3 PIR sensor) are pivotal for constructing robust setups !!reference?!!. Additionally, battery management systems, durable flash units, and noise-dampening materials contribute to the efficacy and longevity of camera trap systems !!reference?!!, !!reference?!!.

Assembly and Setup:

The assembly process plays a crucial role in ensuring the functionality and performance of DIY camera traps. Studies emphasize the significance of securely mounting DSLR cameras within protective cases (Article 4). Clear acrylic windows for flash units, strategic positioning of PIR sensors, and rigorous testing procedures are integral steps in the setup process (Article 3; DIY Camera Trap).

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