EEE4113F Final Report Layout

# Subsystem: Camera/Transmitter and Receiver Hardware Submodule

## Introduction

This subsection involves the design and implementation of the transmitter and receiver module that are essential for a Red-winged Starling nest monitoring system that is tailored to observe this specific species of bird based on the nesting environment. The focus is to capture still images or video footage of the activities in the nest and transmit this data to a handheld receiver for analysis by the user.

The user wishes to observe the niche behaviours of Red-winged Starlings during the critical phases of their nesting period, which include hatching, predation, and fledging. The user is also interested in viewing activities around the nest such as human foot traffic and predators that visit the nest. Currently, most of these important details are missed, which often leads to disappointment. To not miss any more important details, the transmitter module that will be situated on the nest will be designed to trigger the camera if motion is detected in and around the nest. Depending on the amount of motion detected, the transmitter will capture still images and/or videos, providing researchers with valuable information of the Red-winged Starlings’ nesting process. The captured data will be stored onboard the transmitter module and transmitted to a handheld receiver located on the ground. This remote data capture prevents disturbance and avoids causing distress to the Red-winged Starlings.

In this chapter, the user requirements will be addressed, and the design process will be documented. This will include the reason for design decisions, the process of component selection, assembly procedure, and test protocols to validate functionality of the system.

## User Requirements

The user requirements were obtained by interacting with the stakeholders on what is needed in the nest surveillance system. These requirements have minimal technical details; however, help shape the general path towards the final solution seen by the user.

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| **UR1** | **Camera with night vision capabilities.** |
| Requirement | The user requires a camera to view nest activity with reasonable quality and be able to capture footage at all times of day. |
| Rationale | The camera is needed to view the activities in the nest, such as hatching, predation, and fledging. The activities around the nest are also of importance to the user, with regards to the predators, like rats and cats, that surround the nest as well as human disturbance that affect the breeding process. The nest areas may be dark, so the camera module (transmitter) needs to be equipped with additional lighting, that avoids bright lights which may disturb the birds during the nesting period. |
| Verification | Verified by flashing sample code that activates the camera’s different modes to see if all is functional in all lighting conditions, as well as trigger only when there is movement. A test subject will be used as a reference. This will also verify the quoted specifications by the supplier. |

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| **UR2** | **Minimal cables.** |
| Requirement | The user requires the system to have as little cables as possible so that the birds do not use the cables for nesting materials. |
| Rationale | The birds might break the wires to use as materials when building and/or reinforcing the nests. If cables are used, they need to be well protected. |
| Verification | Verified by reducing the number of cables running out of the transmitter to the power supply. |

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| **UR3** | **Control box (i.e., receiver).** |
| Requirement | The user requires for there to be a control box at ground level that wirelessly connects to the camera at the nest to retrieve the data from the transmitter. |
| Rationale | The user prefers for the control box to be situated at ground level, so that there is no need for ladders. The birds get stressed when they see ladders since people can then disturb their nests. |
| Verification | Setup a web server on the receiver that connects to the transmitter to collect data. |

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| **UR4** | **Camera recording** |
| Requirement | The user requires for the camera to only record when there is movement in the nest |
| Rationale | The user prefers for the camera to only be triggered when there is movement, in intervals of one minute between triggers. This would be over the whole nesting period, from laying to fledging. |
| Verification | Test the cameras’ ability to record and store information. |

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| **UR5** | **The transmitter module size** |
| Requirement | The user requires for the transmitter module to be no larger than 8 cm wide x 6 cm high x 6 cm deep. |
| Rationale | The size of the transmitter module cannot be too big. Most of the nests are situated in crevices, so the camera needs to be the specified size, if not smaller, to embed itself into the bird nest environment with minimal disturbance. |
| Verification | Verified by the final size of the internals of the box. The internals need to be smaller than the absolute box size, to account for casing size. |

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| **UR7** | **Long range camera detection** |
| Requirement | The user requires for the camera to be able to pick up movement in the nest from a few meters away, depending on the nest location. |
| Rationale | The location of the nests varies, so the detection range of the cameras and the sensors need to be a few metres at most away from the nest. |
| Verification | Verify that the transmitter can detect the motion from varying distances, using the same test subject as before. |

## Design Process

### Wired vs. Wireless communication

It is worth narrowing down the options to make it easier when choosing between the different microcontrollers available in the market. Below is a table that compares wired and wireless communication to one another with respect to the task at hand.

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| --- | --- | --- |
| **Aspect** | **Wired Communication** | **Wireless Communication** |
| Medium | There is a physical medium made up of cables and wires that run between the transmitter and receiver. | There is no physical media that exists between the transmitter and receiver. Communication is reliant on radio waves to transmit data. |
| Antenna | No antenna is needed since data is transmitted with physical cable connections. | Antenna required to transmit and receive data over long ranges without the need for physical cables. |
| Distance | Works well over shorter distances. As the transmission distance increases, the data quality degrades | Suitable in longer range communication. |
| Power Consumption | Consumes less power since the cables transfer information with little energy loss. | The active components, like the antennas, transmitter, and receiver, consumes more power for data transmission, reception and maintaining a reliable connection. Some low powered options are available (like Bluetooth Low Energy). |
| Speed | Low latency due to physical connections. Ideal when data is required in real-time, such as streaming live footage. | Variable depending on the wireless technology used. However, still suitable in applications needing medium to high-speed data rates. |
| Mobility | Limited freedom to move when there are physical cables. The submodules that need to transmit information to one another need to remain stationary. | High flexibility and mobility are available. Submodules in communication with one another are free to move in the coverage area while still maintaining a reliable connection. |
| Control | Precise control over data transmission can be offered. Fixed connections offer reliable communication. | Lower control since environmental factors such as interferences can limit this. Control is affected by latency as well. |
| Security | Easy to intercept if one has physical access to cables. Vulnerable to cable tapping. | Robust security measures may be implemented. Encryption, authentication, and other secure protocols may be implemented if need be. |
| Maintenance | High maintenance of the physical cable connections. Susceptible to cable wear and tear. Regular inspections needed. | Low maintenance. Software updates may be deployed to improve the system without any need to service the physical modules. |

The nests are located high up on buildings. Wireless communication offers a way to access the data without having to go through the struggle of disturbing the nest daily to collect the data. The Red-Winged Starlings may attempt to break the physical cables in a wired communication setting to use for their nest material. Upon assessing all aspects, the advantages offered by wireless communication outweigh the need for wired communication, despite the issues that come with wireless communication.

### Wireless Communication Protocols

The different options available for wireless communication will be assessed against a set of criteria. The criteria are as follows:

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| **Criteria** | **Justification (Pass/Fail)** |
| **Range & Coverage** | Is the protocol able to transmit data over a range of 10-15 m in an outdoor setting without significant data loss? |
| **Data Rate** | Does the protocol able to operate at a higher data rate? Specifically, could the protocol transmit data at a few hundred Mbps? |
| **Power Consumption** | Is this protocol optimised to work well with low powered battery systems? |
| **Latency** | Does the protocol have a latency lower than 100ms? |
| **Interference & Noise** | Is the protocol functional in crowded frequency bands since the solution will be deployed in an area with human activity? |
| **Cost** | Is this protocol affordable to design and maintain? |
| **Payload** | Is the protocol able to handle large data file transmission? |
| **Existing Libraries & Support** | Does the protocol have available libraries and examples to use? Is there reliable developer support? |

The table below assesses the different options available for wireless communication against the criteria above, and documents whether the protocol passed or failed the justification.

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| --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **Bluetooth Low Energy (BLE)** | **Bluetooth Classic** | **ESP-Now** | **Wi-Fi** | **LoRa** | **RFID** |
| **Range & Coverage** | Fail | Fail | Pass | Pass | Pass | Pass |
| **Data Rate** | Fail | Fail | Fail | Pass | Fail | Fail |
| **Power Consumption** | Pass | Fail | Pass | Fail | Pass | Pass |
| **Latency** | Fail | Pass | Pass | Pass | Pass | Pass |
| **Interference & Noise** | Pass | Pass | Pass | Pass | Fail | Fail |
| **Cost** | Pass | Fail | Pass | Pass | Fail | Fail |
| **Payload** | Pass | Pass | Fail | Pass | Fail | Fail |
| **Existing Libraries & Support** | Pass | Pass | Pass | Pass | Pass | Pass |

Wi-Fi and ESP-NOW both seem like viable options since these two protocols received the fewest fails based on the criteria. ESP-NOW is unable to transmit data at a high rate (only 1 Mbps) and has a very small payload of around 250 bytes. This is only suitable for transmitting small messages between the boards. The issue with Wi-Fi is the power consumption. By reducing the time that the Wi-Fi module is active, the power consumption can be lowered. The other options have lower data rates and lower power consumption. But if the data rates are lower then the module would have to stay on for longer, and while this might consume less power in total, the user would have to wait a very long time for the data transfer process to be completed.

Wi-Fi is preferred. The next part of the design process will look at the choice of camera.

### Transmitter Microcontroller

A microcontroller is needed for both the transmitter and receiver, both of which need to support Wi-Fi to communicate with one another. Some microcontroller solutions come with a camera attachment already, like the ESP32-CAM, while others, like the standard ESP32 WROOM, do not. In the case of the latter, an additional camera module would need to be purchased.

The main suppliers out there with microcontroller solutions are Arduino, ESP, NRF Dev boards, Raspberry Pi Pico W’s, and ST Micro Dev Boards. However, the NRF boards are extremely expensive, and only offer BLE communication, not to mention minimal customer support. The Arduino board options, like the nano 33 IOT and UNO Wi-Fi, are expensive and bulky respectively. The ST Micro Dev Boards are also quite costly in their own regard, since all the affordable options have been sold out, like the STM32F401, but one would need to look at external Wi-Fi modules since those are sold separately. This leaves Raspberry Pi Pico W and ESP boards as the two contenders. 5 of the best options will be picked and assessed on the set of criteria listed in the table below:

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| --- | --- |
| **Criteria** | **Justification** |
| **Processing Power (1)** | Does the microcontroller have enough processing power? How many cores does it have and how high is the clock speed? |
| **Memory (2)** | Does the microcontroller have enough RAM for flash memory to handle image capture? |
| **Low Power Modes (3)** | Does the microcontroller have low power standby modes available? |
| **Power Consumption (4)** | Does the microcontroller consume low power during active mode? |
| **Input/Output (I/O) Pins (5)** | Does the microcontroller have enough I/O pins to support other peripherals or an external camera? |
| **Development Environment (6)** | Does the microcontroller have sufficient development tools readily available? |
| **Cost (7)** | Is the microcontroller affordable? |
| **Size (8)** | Is the microcontroller small and compact? |
| **Existing Libraries & Support (9)** | Does the microcontroller have many libraries available and community support? In other words, is it easy to find resources and troubleshoot? |
| **Onboard debugger (10)** | Does the microcontroller have an onboard debugger or is there a need for an external debugger with an FTDI? |
| **Operating voltage (11)** | Is the operating voltage of the microcontroller 5V? |
| **Camera Support (12)** | Does this microcontroller have good support with regards to camera attachments? |
| **Weight (13)** | Is the microcontroller heavy? Does it weigh more than 30 g |

The table below will now assess each microcontroller based on these criteria:

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| **Criteria** | **Pi Pico W** | **ESP32-CAM** | **ESP32-CH340** | **ESP32-C6** | **ESP32 S3** |
| **(1)** | Dual-core ARM cortex M0+ processor. Clock speed of 133 MHz | Dual-core 32-bit CPU (Low Power).  80-240 MHz clock speed. | 32-bit ESP-WROOM-32 microprocessor. Clock speed of 240 MHz | ESP32-C6-WROOM-1.  Clock speed of 160 MHz | Dual-core Xtensa LX7 CPU.  Clock Speed of 240 MHz |
| **(2)** | 264kB SRAM  2MB Flash memory. | 520 KB SRAM  2 MB PSRAM  32 MB SPI Flash | 520 KB SRAM  4 MB SPI Flash. | 512 KB SRAM  320 KB ROM  4 MB SPI flash | 512 KB SRAM  16 MB Flash memory.  8 MB PSRAM |
| **(3)** | Support for low-power sleep modes as well as dormant mode. | Supports a variety of sleep modes (modem, light, deep). 6mA in deep sleep. | Supports a variety of sleep modes. Light (2 mA) and deep sleep (100µA). | Supports a variety of sleep modes. Consumes 8.14 µA in deep sleep. | Supports a variety of sleep modes. Light (2 mA) and deep sleep (100µA). |
| **(4)** | 25mA current draw in idle mode. | 180 mA no Flash / 310 mA with Flash | When in normal mode, current draw 95-240 mA. | When in normal mode, current draw 23.88 mA. | When in normal mode, current draw 95-240 mA. |
| **(5)** | 26 multi-function GPIOs | 9 GPIO ports | 2x19 pin extension headers. | 31 multi-function GPIOs | 45 Programmable GPIOs |
| **(6)** | Drag & drop programming using mass storage over USB. | Supports various development environments. | Supports various development environments. | Supports various development environments. | Supports various development environments. |
| **(7)** | R147.20 | R235.00 | R147.20 | R285.20 | R204.70 |
| **(8)** | 21mm(W) x 51.3mm(L) x 3.9mm(H) | 27mm(W) x 40.5mm(L) x 4.5mm(H) | 28.5mm(W) x 51.5mm(L) | 28mm(W) x 53mm(L) | 13mm(W) x 50.1mm(L) |
| **(9)** | Very well supported with a large community and variety of libraries to choose from. | Very well supported with many libraries available. | Very well supported with many libraries available. | Very well supported with many libraries available. | Very well supported with many libraries available. |
| **(10)** | Has one. | Needs an external FTDI | has a USB-to-UART bridge for communication. | Has a dual USB C interface for debugging and firmware update. | has a USB-to-UART bridge for communication. |
| **(11)** | 4.5V – 5.5V | 5V DC | 3.3V – 5V | 3.3V – 5V | 4.8V – 5.2V |
| **(12)** | Support for Arducam. | Support for OV2640 & OV7670 | External OV7670 | None that are well supported. Alternative is to have an I2C camera. | None that are well supported. Alternative is to have an I2C camera. |
| **(13)** | 4 g | 20 g | 10 g | 10 g | 10 g |

Verdict:

Upon looking at the table above and assessing all the specifications head-to-head, a firm decision can be made on which microcontroller to pick for both the receiver and transmitter sections to host the wireless connection for data transmission.

Firstly, all microcontroller options support the same Wi-Fi, EEE 802.11 2.4 GHz. When it comes to the transmitter, the most important thing is the camera. All options except for the ESP32-CAM do not ship with a camera in the box. ESP32-CAM is the most expensive of the lot, but if you factor in the cost of an external I2C camera, like the OV7670 which costs R60.00, it brings the price neck and neck. When researching the other options, I checked for the support available when it comes to implementing an external camera, and every forum gave me the same answer – the ESP32 CAM is the way to go. It has some of the best software support out there. Even though the ESP32 CAM has the fewest GPIO Pins, the OV7670 requires 8 wired connections to the microcontroller, and needs to also be powered separately. Note that there are other external cameras available, however they were out of stock or discontinued in the region.

The strengths of the ESP32 CAM make it an attractive option. With Quad SPI, it has some of the fastest read/write speeds to the microSD card, which just so happens to be on board, eliminating the need for an external module. It has the highest clock speed of the options available. The drawbacks are just the price and need for an external FTDI. Luckily for the price, the FTDI ships in the box. The ESP32 CAM also ships with the OV2640 camera in the box that connects via a tag. The minimal GPIOs are not an issue since this has been accounted for in the final design. The ESP32 CAM also comes with the option to add an external antenna, should the user wish to extend the range of transmitter.

The choice was made to pick the ESP32 CAM as the transmitter microcontroller given what was discussed above.

### Receiver Microcontroller

The receiver module is a handheld device that the user can turn on and off when they please. It needs to be reliable enough to get the job done while being affordable. The task at hand is to host the server for the ESP32 CAM to connect to so that the user can download the data onto an SD card in the receiver module. No camera is needed so the ESP32 CAM immediately becomes irrelevant. Most of the other ESP options are still quite costly except for the ESP32-CH340, which is the same price as the Raspberry Pi Pico W. The ESP chip is computationally superior; however, it is much larger and heavier than the Pi. Weight and size is a factor here since the user will be interacting with it, but even more importantly, the casing for the receiver is tight so any space saving is ideal. I visited several forums, and based on the task I was willing to do, the Raspberry Pi was more reliable when other fellow engineers deployed similar tasks. I then consulted with Robert, the person developing the software interface, and he preferred to work with the Raspberry Pi Pico W since he was already familiar with how to operate the Pi.

The choice was made to pick the Raspberry Pi Pico W as the receiver microcontroller given what was discussed above.

### Sensors & Peripherals

This constitutes the surrounding components that support the data transmission process.

PIR

Infrared Light

433MHz RF Link Kit

MicroSD card SPI

LCD Display

## Functional Requirements

The functional requirements are more detailed and build on the user requirements. The end user would not necessarily know what the technical details are of their desired product, this is more for the engineer designing this submodule.

## Constraints

The birds hate cameras staring directly at them, they tend to attack. The current solution is having a gopro mounted to a pole that peers into the nest, but the birds hate this.

## Design Process

For micro, split between the different options. You’ve got:

* ESP,
* Raspberry Pi,
* Arduino,
* STM.

## Final Component Choices

## Final Assembly

## Validation Test Procedure

### Acceptance Test Protocols (ATPs):

Transmitter

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| --- | --- | --- | --- |
| **Code** | **Description** | **Test condition** | **Pass/fail** |
| ATP1.1 | The camera is initialised. Still images and videos are captured in different lighting conditions and at various distances, within the range stated on the datasheet. |  |  |
| ATP1.2 | An object is moved in front of the PIR sensors at different distances to check if they detect movement at the ranges quoted on the datasheet. |  |  |
| ATP1.3 | An object is moved in front of the camera module at varying distances to see if it starts recording when motion is detected. |  |  |
| ATP1.4 | The infrared diodes are turned on in a dark area to check if they improve the camera quality. |  |  |
| ATP1.5 | A power source has been designed to power this transmitter. The system was connected to evaluate its performance over 24 hours. The power consumption of the components in this module will be tested during this time. |  |  |
| ATP1.6 | The mic quality is tested to see if the sound recorded is useable. |  |  |
| ATP1.7 | The finished transmitter is then placed in a controlled area where a simulated bird is used to see if the camera starts recording when there is movement. The lighting conditions and trigger distances are also varied. |  |  |
| ATP1.8 | False triggering is then tested. In other words, the accuracy of the PIR sensors. |  |  |
| ATP1.9 | The ability of the transmitter module to read and write data to an SD card is tested. |  |  |
| ATP1.10 | A continuity test is done on the final board to evaluate that there are no shorts on the board or any components. |  |  |

Receiver

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| --- | --- | --- | --- |
| **Code** | **Description** | **Test condition** | **Pass/fail** |
| ATP2.1 | The display screen on the receiver is tested to see if it can display simple text. |  |  |
| ATP2.2 | The power switch on the receiver is tested to see if it powers up the receiver. |  |  |
| ATP2.3 | The pushbuttons on the receiver is tested. This is done by checking if the buttons are functional and are correctly connected to the rest of the receiver. |  |  |
| ATP2.4 | The RF receiver module capabilities are tested. This is done by checking if the RF module can remotely wake up the transmitter module from sleep mode. |  |  |
| ATP2.5 | The receiver connection to the transmitter is then tested. As stated previously, the receiver establishes the connection which the transmitter will connect to. A test is done to see if this can be done, and if the power consumption matches the datasheet. |  |  |
| ATP2.6 | The ability of the receiver module to read and write data to an SD card is tested. |  |  |
| ATP2.7 | The power consumption of the module will be tested when the designed power source is connected to see if it matches with the datasheets of individual components. |  |  |
| ATP2.8 | A continuity test is done on the final board to evaluate that there are no shorts on the board or any components. |  |  |

## Conclusion

For the LED, ,   
 is the saturation voltage for 2N2222A.

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