Developing a Remote Digital Wildlife Camera Triggered by Spatially Deployed Infrared Sensors

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***Abstract*—This paper describes the design, construction, and operation of a system devised to capture images of wildlife with a full 360 degrees of view. The system uses infrared detection in a circular configuration to detect movement of heat signatures and then relays that information to a base station via short distance radios. The base station uses a microcontroller to take this information and turn a camera using a stepper motor. When the camera is in the correct position it is triggered to take a picture. Images are stored on an internal SD Card, and are then transferred to a remote location via long distance radios where a user can view captured images without manually retrieving them.**

Keywords- Wireless Sensor Network, Stepper Motor, 8051 Microprocessor, ePIR Sensor, XBee Radio

I. Introduction

The main motivation driving the work done throughout the Electrical Engineering Summer Research Experiences for Undergraduates (REU) was to improve the current technology available to wildlife researchers and hunters through the enhancement of wireless embedded system instrumentation. This was achieved by the design and fabrication of a system capable of using infrared sensors arranged along a perimeter that wirelessly communicate with a base station that uses a stepper motor to turn a camera towards a detected moving heat signature and then take a picture.

Section II describes previous work done in the field of automatic wildlife imagery; Section III provides an overview of the system and details all of its components; Section IV describes how the system operates; and Section V discusses our results and conclusion with future work.

II. Previous Work

There are several companies that manufacture and market cameras designed for wildlife research and scouting. One major problem with these digital wildlife cameras is the limited range of their sensing mechanism and corresponding viewing area. Most game cameras use a single differential passive infrared (PIR) sensor configuration mounted in a fixed direction to detect the heat signatures of passing game, which triggers the camera to take its picture. The problem with this sensing mechanism is that it is singular in its point of focus and covers a narrow area defined by the camera's field of view and the acceptable sensitivity range of the embedded sensor. A typical configuration would capture activity on a known trail within a wedge shaped area of approximately 440 square feet. This is highly inadequate for monitoring most fields, which are normally much larger than 30 feet across, such that much of the wildlife passing through may not trigger the sensors, and therefore the camera will not take their picture.

III. Overview of System

This project developed a remote access digital wildlife camera. To achieve the objective, multiple wireless nodes equipped with PIR sensors were deployed in a circular configuration, thus forming a monitored perimeter with a digital camera at the center. The game camera was mounted on a microprocessor controlled stepper motor. When one of the sensors detects the heat signature of passing wildlife, the digital camera is directed to turn toward the sensor and record a still image. This configuration expands the monitored area by creating multiple image zones, which are determined by the maximum sensitivity (range) of the sensors, image collection strategy (i.e., the camera lens field of view), and number of images taken in each zone. In order to simplify the required camera control interface a fixed focal length lens was utilized. Since multiple sensor nodes were deployed, the radius and therefore the total coverage area of the monitored zones was constrained only by the resolution of the camera and the effective distance of the flash for low light image acquisition.

A. Base Station

The base station is comprised of several elements including: a camera, stepper motor, 8051 microprocessor, 2.4GHz and 900MHz XBee Radios, and a power supply sourced by a 12 volt battery.

i. Camera

While reviewing cameras, several different makes and models were considered, from commercial point and shoot, digital SLR, and specialized industrial cameras. The final decision was to buy and modify a refurbished commercial trail camera. The Moultrie Game Spy I65 Digital Trail Camera was chosen based on its features and price. Besides having four picture resolution settings and a built-in infrared lens and flash, this camera came with many additional features that are well suited to its intended purpose. The wide viewing angle of the camera helps ensure that the system captures pictures of animals under a broad set of circumstances including multiple animals passing simultaneously, animals moving laterally across the field of view and directly toward the camera, and animals that have moved past the trigger point while the camera is positioned and prepared for image capture. The lens of the camera is fixed but provides an adequate focus distance. A major advantage of this camera is that it automatically switches to an infrared mode in night time shooting conditions and includes an integrated IR LED flash that was tested as effective up to 50 feet in night time conditions. The camera is also easily accessible, meaning that it is very simple to open and manipulate, and is housed in a waterproof case, as shown in Fig. 1, which makes it ideal for its intended use. The camera is capable of operating from a 12 volt input that allows us to use a standard deep cycle 12 volt lead acid battery as its power source, which can also be used to drive the stepper motor with adequate torque. A final feature is the camera's information bar, which imprints each picture with time, date, moon phase, temperature, and barometric pressure. All of this information could be viable in studying the habits of wild game.

Figure 1: Camera in Weatherproof Enclosure

ii. Stepper Motor

One of the main components of the base station is the stepping motor. By utilizing the stepping motor's full range of rotation, the viewing field of the camera was increased from 52 degrees to 360 degrees. The stepping motor is an Airpax brand, 6 volt, 5 ohm, 1.8 degrees per step device. While it is rated for 6 volts, it was driven by the 12 volts coming from the power supply. The stepping motor is a 6 wire motor and is therefore capable of bipolar operation, but for ease of use the wire leads coming from the nodes connecting each of the two half stators together have been left floating so that the motor operates as a unipolar stepping motor. Unipolar stepping motors are easier to use considering that their pulse timing is not as critical since their configuration does not lend to shorting current over multiple transistors. The two windings within the stepping motor are driven by their own individual UC3770B Stepper Motor Drive Circuits. These circuits control and drive the current of their respective windings.

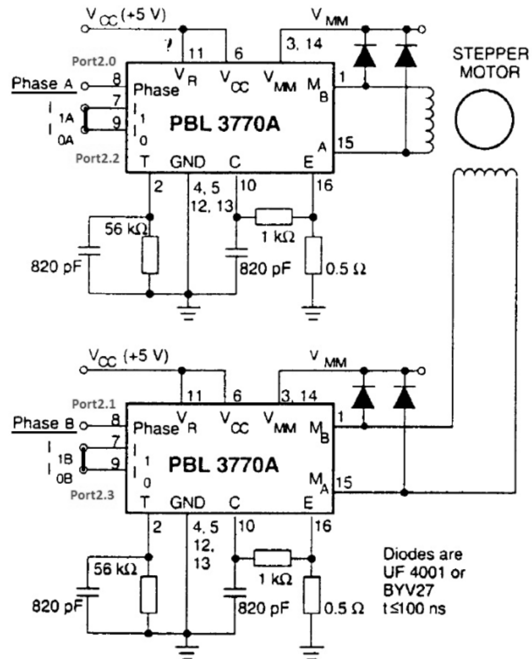

Figure 2: Stepper Motor Control Circuit

The Phase, I_0, and I_1 pins control the direction and speed of the stepper motor as shown in Fig. 2. Each whole motor step increment requires an 8 step sequence diagramed in Fig. 3.

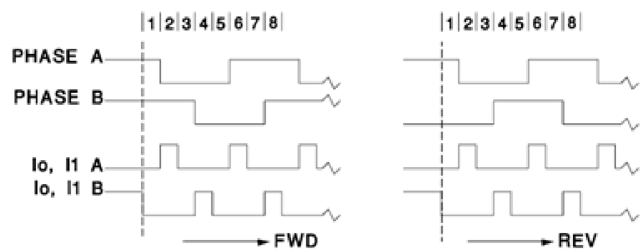

Figure 3: Stepper Control Logic

The stepping motor described above is part of a gear system that was salvaged from a decommissioned custom lab instrument. The gears were rearranged from a 10:1 ratio to produce a 2.5:1 ratio. That is 2 ½ motor rotations will make one full rotation of the turntable. The turntable is where the camera is mounted, so this gear ratio allows for more accurate positioning of the camera. On the shaft just under the turntable is a collar with one small slit. Around this collar a Photologic OPB972 slotted optical switch is positioned in order to help calibrate the camera. The switch outputs a logic high unless the turntable is in the location such that the slit is positioned where the infrared passes through the slit and is received by the collector. Using this switch configuration allows the user to know exactly where the camera is positioned.

iii. Base Station Circuitry

The base station serves as the hub of the system both physically and logically. Its primary purpose is to: coordinate, prioritize, and respond to the signals from the sensor nodes and the remote management node; control the digital camera and manage the image acquisition process by controlling the digital camera shutter release and stepper motor positioning circuits; and provide a method for a remote file retrieval service for the remote management node.

The base station was designed as an embedded system with a Dallas Semiconductor DS89C450 [1], which is an Intel 8051 microcontroller variant that provides up to 64K of program space, one instruction per clock cycle at 11.0592MHz, and 4 eight pin I/O ports including two UARTs for serial I/O and on chip programming. The communication sub-system consists of a short distance (up to 300’ line of sight) 2.4 GHz, 1mW, IEEE 802.15.4 radio [2] for interacting with the sensor nodes and a long distance (up to 1.8 mi. line of sight) 900 MHz, 50mW radio [3] for communication with the remote management node.

The camera subsystem provides a weatherproof enclosure for the camera, integrated IR flash, base station circuit board, both radios, and all interfaces to the stepper motor and external power supplies.

As shown in Fig. 4, the layout of the main base station circuit board was determined by the relative location of interfaces to both on and off-board components and subsystems. In order to minimize the demand of limited on-board real estate the 3.3V, 5V, and 12V power supplies are located in an external enclosure. In addition, the DB9 serial programming port is to be brought to an external location while the RS232 to TTL level shifter will remain on the main circuit board. If desired the 8051 could be programmed by physically removing the chip and placing it in an external programming platform which could reduce wiring congestion and free up space by eliminating the in-circuit programming capability. This would reduce the space requirement by approximately 1.5 square inches by removing two LM3904 transistors and several bias resistors along with the MAX202 level shifter and charge pump capacitors. The camera enclosure provides enough space for a second smaller circuit board that will host a Vinculum USB host controller chipset [4] to be used as an interface to the camera SD card storage subsystem, as shown in Fig. 5.

iv. XBee Radios

The communication sub-system will consist of a short distance (up to 300’ line of sight) 2.4 GHz, 1mW, IEEE 802.15.4 radio [2] for interacting with the sensor nodes and a long distance (up to 1.8 mi. line of sight) 900 MHz, 50mW radio [3] for communication with the remote management node. These radios are mounted to the back covering of the camera with leads running to the microprocessor board inside of the camera enclosure.

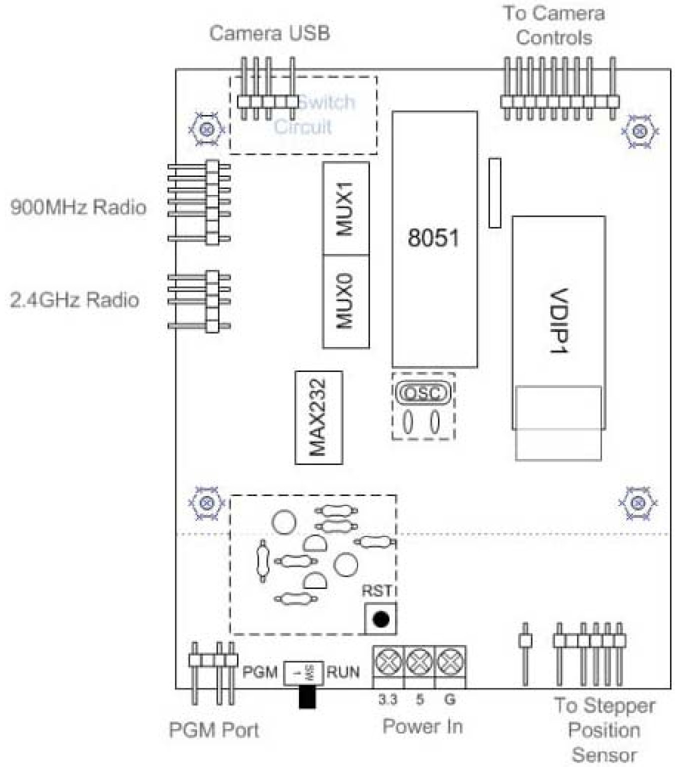

Figure 4: Base Station Block Diagram – Bottom Tier

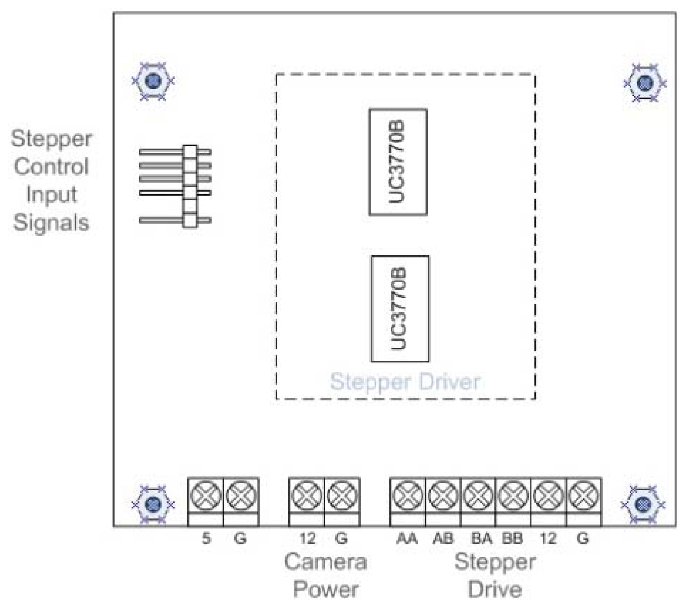

Figure 5: Base Station Block Diagram - Top Tier

v. Base Station Power Supply

To extend the service life of the entire system, a 12 volt battery was implemented into the design, as shown in Fig. 6. The power source consists of Step Down (Buck) converters that use pulse width modulation to bring the 12 volt source down to 3.3 volts and 5 volts, both rated for 3 amps. The power supply has in line fuses and diodes to prevent damage to any circuitry if polarity on the battery is accidentally reversed or if too much current is being drawn. Lastly, the power supply has a simple single pull single throw switch for easily turning the power to the base station on and off. LM2576 switching regulators rated for 5 volts and 3.3 volts were implemented. Also on the power supply box is a single pull single throw switch tied to a pull up resistor through a 5 volt source that acts as our calibration switch.

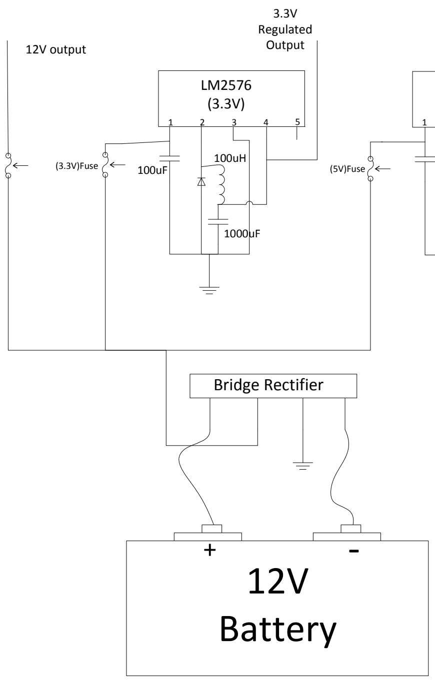

Figure 6: Base Station Power Supply Schematic

vi. Base Station Construction

Since our final product was to be field operational, many precautions were taken to ensure that the system could endure a variety of weather conditions typical of our location. All circuitry chosen was rated to withstand temperatures well within the norm of North West Arkansas. However, our main concern was making the system water-proof. The power supply was built inside of a project box, and then placed with the battery inside of a battery box. The stepping motor was mounted inside of a section of 6 inch PVC tubing with only the mounting bracket for the camera exposed at the top. The camera itself is waterproof, and the whole system sets on top of a surveyor's tripod, which is capable of being adjusted for leveling and height purposes.

B. Remote Sensing Nodes

The main components of the remote sensing nodes include: ePIR sensors, power supply, and the 2.4GHz XBee radio.

i. ePIR Sensors

The product chosen for the motion detection was Zilog's ePIR Motion Detection Zdots Single Board Computer (SBC). This product is a complete motion detection system that has a PIR sensor (passive infrared) and a Fresnel lens and comes pre-programmed with motion detection software. Its sensitivity parameters are controlled via simple hardware configuration. The important factor for choosing a sensor was the detection pattern. The area covered by the ePIR, or range, is maximized by using it in Extended Range Mode. This actual distance depends on the sensitivity setting but it ranges from 3 meters by 3 meters to 5 meters by 5 meters with a 60 degree angle. Preliminary tests indicated that the range of detection was indeed up to 5 meters but held most consistent up to 4 meters. It has a digital output so that when motion is detected the output is 0V, and 5V when no motion is detected. The detection is most reactive to motion perpendicular to its pattern which is what determined the optimum configuration of the sensors around the base station.

With a few options for configuring the sensors, the objective was to minimize the number of sensors required to ensure full coverage (minimize cost) as well as maximize the efficiency of the range. The first sensor formation that was considered was an array of sensors facing one direction where each node would be placed at the exact range distance with no overlap. The lack of overlap was to minimize the number of sensor nodes required. It was decided that if the detection range for some reason wasn't as consistent as its specs specify there would be a possibility of misdetection, which is why the second formation was considered. This formation was just a slight variance of the first being that there would be overlapping. The tradeoff for this formation was the higher accuracy over the expense of adding more sensor nodes to our system. The final configuration decided was to place two sensors on each sensor node at an angle of X to meet the requirement of covering a radius of 40ft from the base station. With this formation, the number of radios necessary was cut in half and the overlapping range of coverage by each ePIR was addressed. As shown in Fig. 7, each sensor node covers a 40 degree zone from the camera in the center, requiring 9 sensor nodes to cover all 360 degrees.

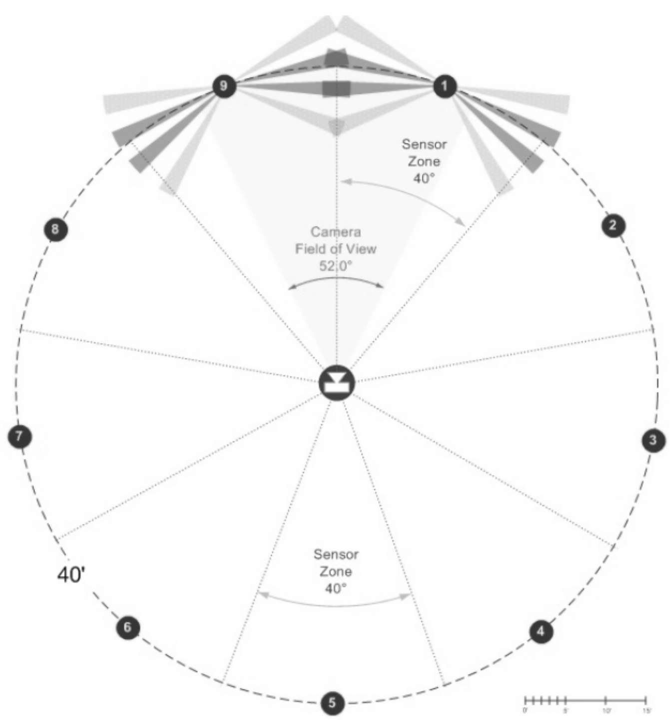

Figure 7: Sensor Node Coverage Pattern

ii. Node Power Supply

Size and longevity were both considered when choosing a power source for the nodes. After weighing the advantages and disadvantages of several different sources, it was decided to use packs of two C-Cell batteries per node. These C batteries were believed to give the best power output for their size and were easily adapted into node construction. As shown in Fig. 8, Max756 chips were used to step the voltage output of the batteries up to a regulated 3.3V. Stability was a main factor when choosing the Max756 for the radio's source voltage, since when this varies within a few hundred mV, the packets become distorted and inconsistent. This converter accepts all the way down to .7V input and converts it to a stable 3.3V or 5V depending on its configuration, with 87% efficiency at 200mA.

iii. Node Construction

The nodes were placed in a PVC enclosure comprised of a 4 inch DWV Female Adapter, a 4 inch cleanout plug, and a 4 inch cap. On the bottom side of the cleanout plug a 1 inch plug was attached and tapped for a ¼ 20 bolt. This allowed us to fasten the nodes to 3 foot iron stakes. The PVC enclosure was drilled for the two ePIR sensors to point out of. We then used clear silicon to secure the ePIR sensors into place and to prevent water from entering the node. The power supply and 2.4GHz XBee radio were also put into the enclosure along with an on off switch and a calibration button.

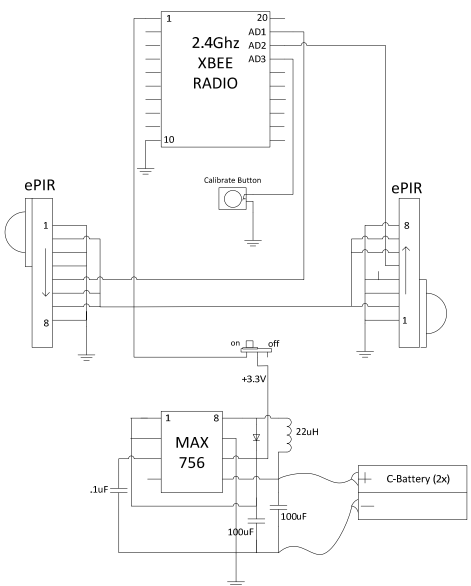

Figure 8: Sensing Node Circuitry

C. Remote Management Node

A remote management node was constructed consisting of an XBee Pro 900MHz, 50mW radio and an FTDI USB to UART interface. This unit can be tethered to a PC. Drivers are readily available for most common operating systems and provide a virtual com port that can be addressed with a simple terminal program to facilitate the bi-directional communication with the Base node. The radio is configured for operation at 115,400 baud, 8 data bits, no parity and 1 stop bit. The remote node hardware is powered from the USB port and has an external RP-SMA connector for a 900MHz quarter wave antenna.

IV. Software Design

The functional logic of the base station is implemented as a simple finite state machine. There are three primary operational states, shown in Fig. 9: Idle, Sense, and Manage.

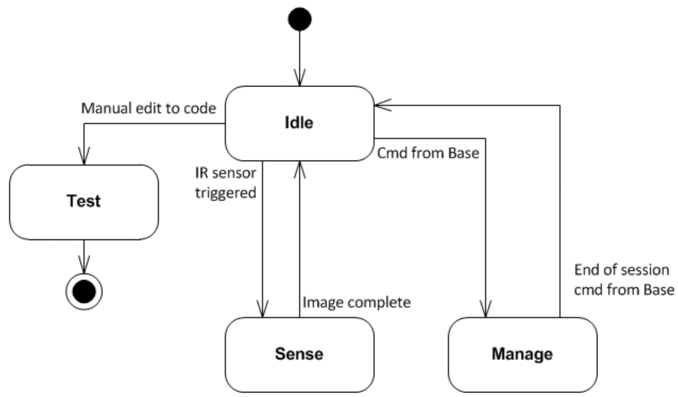

Figure 9: Finite State Machine

In addition a fourth test state can be utilized for future system development and verification by manually altering the code but this state is not active in normal operation.

Once powered up, the base station sits in the Idle state waiting for a byte stream from one of the two base radios. The arrival of a byte from one of these radios will invoke an interrupt service routine associated with one of the two 8051 UARTs. The ISR will set the software defined state variable to the appropriate state value, Sense or Manage, and perform minimal processing before surrendering control to the finite state machine code segment.

A received packet from one of the sensor nodes via the 2.4GHz radio on serial port 1 will cause the finite state machine to transition to the Sense state. It will remain in this state and perform stepper calibration, camera position, and image acquisition sub-states or actions until a complete image cycle has occurred as shown in Fig. 10. Upon completing an image acquisition cycle, it will transition back to the Idle state.

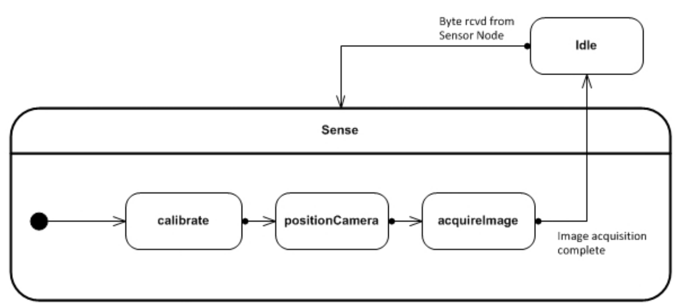

Figure 10: Sense State

When a command byte is received from the remote management node via the 900 MHz radio on serial port 0 the system will transition to the Manage state. The primary

Manage state envelops sub-states and actions necessary to respond to a remote management node as shown in Fig. 11.

Each sub-state corresponds to or supports a command request from the remote management node and additionally provides the initialization routines required to communicate with the camera's SD card storage system via the Vinculum VDIP USB host controller. Once the initialization routines have established a communication link with the camera file system, individual files may be retrieved by the remote node one at a time by sending a four byte command from the remote management node to the base station.

A simple command protocol was created as shown in Fig. 12. Each command consists of a four byte sequence that begins with a command flag byte (0xE7), followed by a command ID byte (0xC0-0xCF or 0xA0-0xAF), a parameter byte for command arguments, and a command termination flag (0xE8). For example, the command to request file number 10 from the camera would be formulated as the four bytes: **`0xE7 0xC2 0x0A 0xE8`**. Each byte is sent as a hex value with no carriage return or line feed within or at the end of the string.

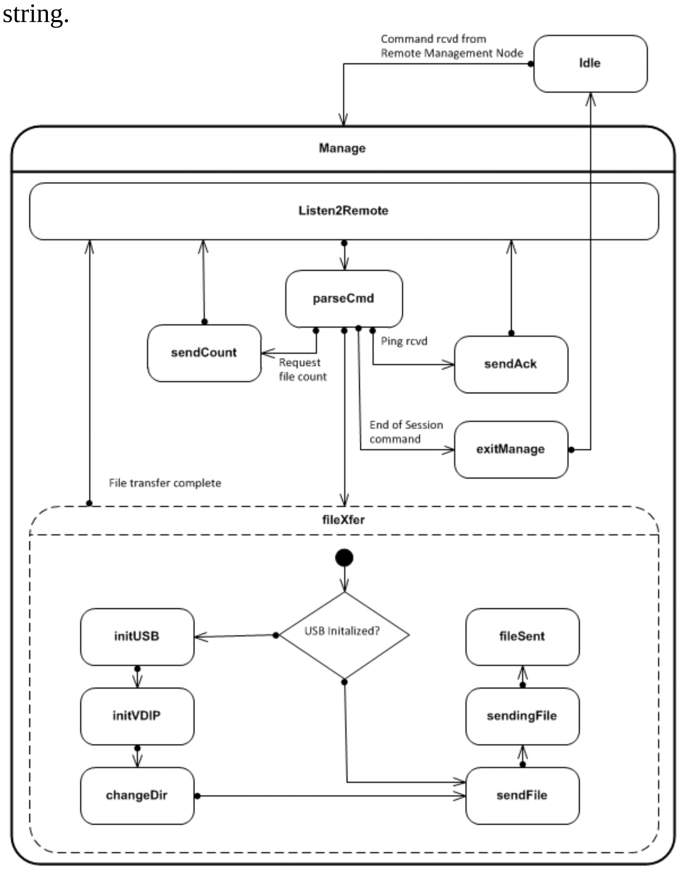

Figure 11: Manage State

The 16 available command IDs from 0xC0 to 0xCF are reserved for commands from the remote management node to the base. Command IDs from 0xA0 to 0xAf are responses sent from the base to the remote management node.

The camera images are recorded in medium resolution JPEG EXIF format. The base station processes the file request command by converting the file number parameter into a properly formatted file name for the camera file system such as PICT0nnn.JPG where nnn is replaced by the decimal converted hex value sent as a parameter. All bytes are sent as a continuous stream until the base station detects the end of the file. The base station will send an A9 command string to the remote node to signal that the file transfer is complete.

The Manage state must be terminated by the remote node via an End of Session command C9. Upon receipt of this command the base station will disconnect from the camera file system by removing power from the USB interface and return to the base station Idle state.

Command ID	Description	Parameter
C0	Ping remote	none
C1	Get file count	none
C2	Request file	Hex byte
C9	End Of Session	none
A0	Remote ping response	0x01
A1	File count	Hex byte
A9	End of file transfer	none

Figure 12: Command Protocol

V. System Operation

To operate the system, the first thing required is to set up the base station and sensor nodes. The base station that sits on top of the surveyor’s tripod should be leveled and approximately 4 feet off the ground. Once this is in place the system should be turned on and switched into calibrate mode. While in this mode pressing the calibrate button on any of the sensing nodes causes the camera to turn and face the direction where the node should be placed. To help with alignment the camera itself is switched into aim mode which lights an LED on the face of the camera. Users can utilize this light along with a measuring device of 40 feet to locate the exact position of every sensor node. The node is also marked so that the enclosure should face the camera correctly and align the ePIR sensors properly.

It is important to note that before the camera turns towards the correct location, it returns to its home position, which is known by the use of the Photologic OPB972 slotted optical switch. This is to prevent miss positioning the nodes due to the camera being manually turned or a gear slipping. Another reason for implementing this switch is to keep the camera from turning more than 360 degrees. If the motor is turned more than 360 degrees without the OPB972 switch being triggered, the system is shut down. This is to prevent the camera from constantly turning in one direction which would twist and break the wires running through the shaft of the motor hardware.

Once the system is set up, the calibrate switch is flipped to sense. This turns the camera on so that it is ready to snap a picture, and also has the microprocessor looking for radio packets that tell it where to point the camera. By default the camera is at its home position until it receives an order to turn a certain direction.

There are two identifiers when decoding a packet received from a tripped motion sensor: one is the radio nodes (1-9) and the other is which side of the node it is, left or right. The decoding process of these 14 byte packets includes entering an interrupt service routine where it processes each individual byte. For these packets byte 5 defines which radio is being triggered and byte 12 defines which side is being triggered. The radio node and side are called in a function of code that moves the stepper motor to point in the appropriate direction.

Once the camera is turned towards the heat signature that has tripped the ePIR sensor, it is then pulsed to take a picture. The camera has a sleep function that takes effect after 100 seconds of inactivity. If in sleep mode, the camera takes approximately 12 seconds to wake up. The code is set to recognize if the camera is in sleep mode and enter a subroutine to wake it up and wait an appropriate amount of time before capturing an image.

Another feature of the system is its nighttime operation. The ePIR sensors function well in lowlight conditions and the camera has a light sensor which switches between daytime and nighttime pictures. The camera has an infrared flash and lens which are automatically deployed when low light levels are detected.

Files can be retrieved remotely using the remote management radio node. A terminal communication program such as Hyperterm or RealTerm is required to send commands to the base station and receive the image files from the base station. Each command from the remote node consists of four bytes as described in Section IV. When a command is sent to the base station from the remote management node, the base station will respond with the appropriate data. If a file is being retrieved, the remote management node terminal software must be ready to capture all of the bytes and save them to a file as there is effectively no delay between receipt of the command and the initiation of the data stream. The base station will send the four byte sequence of 0xE7 0xA9 0x00 0xE8 to indicate that the file transmission is complete. The remote management session must be terminated by sending the End of Session command to the base station.

VI. RESULTS, CONCLUSIONS, AND FUTURE WORK

The final design operated as intended. The calibration mode made setting up the sensing nodes simple. Switching into sense mode allowed the camera and motor to operate simultaneously with correct timing to obtain high quality still images when a packet was transferred and received by the 2.4GHz XBee radios.

There was some difficulty with receiving false triggers from the ePIR sensors. The exact source of the problem is unknown but some probable causes could be the high ambient temperature observed while testing, movement of vehicles and trees, and the reflection of the sun off of surrounding buildings. A possible solution to reduce these false triggers would be to attach a CDS photo cell to the light gates of the ePIR sensors. This would give a voltage to the light gate proportional to that of the ambient temperature.

One other design problem encountered was an excessive amount of noise in the voltage lines which seemed to be produced by the stepping motor circuitry while the motor was still with holding torque. This was a critical issue as the excess noise would not allow for the base station radio to distinguish packets coming from the node radios. A solution to this problem was to run a separate ground from the power source straight to the stepping motor circuitry. This seemed to reduce the noise and allow the base station 2.4GHz radio to receive packets from its node counterparts.

In conclusion, the design and implementation of the project was a success as all of the subsystems worked together to achieve the image capture of moving heat signatures. Our final system increased the viewing angle of the camera from 52 degrees to a full 360 degrees at a 40 foot radius, increasing the image capture range from 726 ft^2 to 5026 ft^2. This much broader scope should capture images of wildlife that would not be photographed by today's leading wildlife cameras.

Future work could include enhancements to the remote management functionality by providing custom software to provide more remote control features such as on demand image acquisition, automated multiple file transfer, and error and flow control options. This software could also provide the ability to view and catalog images dynamically. A more elaborate front end would include a command driven interface to provide camera file management tasks such as rename or delete, and camera image parameter controls such as resolution. This feature set would require additional hardware modifications to the base station to provide access to additional camera controls.

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