Capstone Project Proposal

Loose Screws

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Contents

List of Figures

1 Abstract

Radiance is a surveillance and intruder detection system that uses thermal imaging to detect any life within a designated perimeter, automatically illuminating the entity and tracking its position as it moves. A Raspberry Pi will analyze images from the thermal camera in real-time, identifying potential intruders using their heat signatures and silhouettes. This software analysis will then serve as input to the microcontroller, which will precisely drive motors to orient the system to point at the identified intruder. The light will receive a signal from the micro-controller as soon as the intruder is within the illumination zone. The system will also include a web server which will allow users to view the thermal feed overlayed with information from the analysis, as well as be able to manually control the system to illuminate any points of interest inside the perimeter. This project is an example of computer vision and autonomous robotics in security, a field that has expanded into the consumer market from military technology [1].

2 Background

Automated and reliable surveillance technology has a wide range of applications. Government and military institutions have systems that utilize a myriad of sensors and detection systems capable of finding anything from intruders to intercontinental ballistic missiles entering a designated perimeter. Unfortunately, systems such as these are prohibitively expensive for the average consumer. Looking at the commercial market, the options available often struggle with accurate intruder identification under all lighting conditions or are not autonomous and require continuous monitoring in order to achieve real-time detection. Radiance addresses these issues by providing an affordable system capable of automatically and accurately detecting intruders. Furthermore, the ability to illuminate potential targets allows users to quickly locate and engage with intruders. The task of accurately detecting intruders, whether they be people or animals, requires clear imaging under all lighting conditions. Most commercial surveillance systems such as Simplisafe's Wireless Outdoor Security Camera use a visible light camera with a motion activated floodlight for nighttime surveillance [2]. This is a simple strategy, but often runs into false activations as the motion sensor can be easily triggered by anything from a car driving by or a bird flying through the yard. Night vision cameras such as the Lorex Nocturnal 4 Smart IP Bullet Cameras [3] are another popular option. They are infrared (IR) cameras which work by shining a short wavelength IR light over the entire field of view and detecting reflections off objects[4]. Unfortunately, due to its lack of color, objects are often difficult to identify off of IR video. Furthermore, for real-time intruder detection, the user would have to continuously monitor the video feeds as there is no alert system. Researchers at the Glasgow Caledonian University used image processing techniques to differentiate people and other moving objects from a monochrome video feed [5]. The researchers recognized that most of the time, security personnel are watching nothing happen on the dozens of video feeds they need to monitor. This quickly leads to fatigue and ultimately leads to errors. The goal of this project was to create a tool that would identify potential threats for guards to further investigate such that the personnel wouldn't have to continuously watch the feeds manually. Radiance will build upon the findings of this research project and will apply the same principles in a product more applicable to home security. The use of a more advanced camera as well as the lighting hardware will provide an all-in-one system which will equip users to quickly and precisely detect intruders. This project will draw on countless topics covered throughout the Electrical and Computer Engineering (ECE) coursework at the University of Virginia. PCB and circuit design principles from the Fundamentals series will be critical to the development of this project. Analytical, numerical, and experimental verification of our design will be a significant part of our testing process. The Embedded Computing and Robotics series will also be the foundation for much of the project's design as experience with the MSP432 microcontroller and interfacing hardware with software will be essential during the development phase. On top of the ECE coursework all team members have completed, Minsol has experience with computer vision and object tracking from a research internship. Kousuke also brings experience designing power supply circuits and Josh completed an internship focusing on security and professional software development practices.

3 Project Description

3.1 Performance Objectives and Specifications

The performance of our system will depend on many external and internal factors (described under major challenges) that will limit the capabilities of our system. Based on those considerations, the baseline of our performance goals will be as follows: given that the system is monitoring a 5 m x 5 m x 5 m volume (as depicted in Figure 1), it will be able to shine a light on a single subject that is moving at a top speed of 2.8 m/s across any direction of the room with a precision of $\pm$ 0.15 m in either direction in the worst case scenario (refer to technical details for calculations). The speed quantity being used was characterized as a fast speed in a study regarding human running speeds [6]. In the event that another subject is recognized by the software, the light will stay on the object that was first recognized, but a toggle functionality will be available to the user if switching to the next closest detected subject is desired. As described previously, the user will also be able to access a live feed of the thermal camera remotely with relative ease. Lastly, the system will not activate while there is still sunlight (if outdoors).

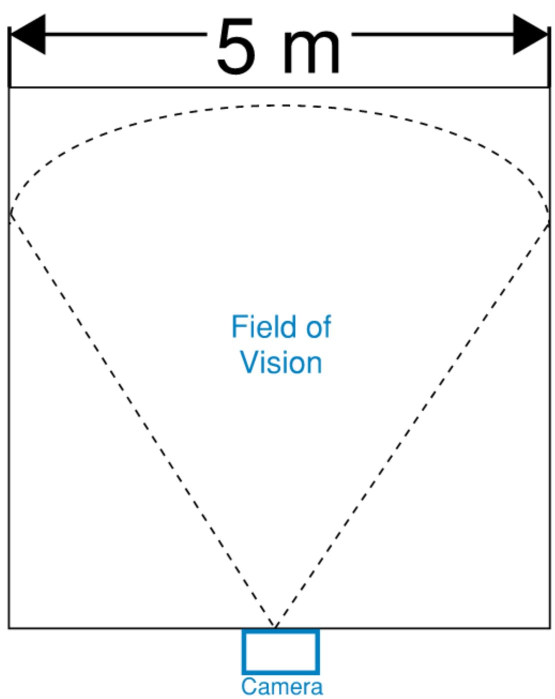

Figure 1: Baseline Performance Camera Setup (Top view)

3.2 How It Works

The final vision of our design will consist of several components of equal importance that will work together to achieve the performance goals that were stated above. The following diagram shows the high level structure of the system that will be implemented.

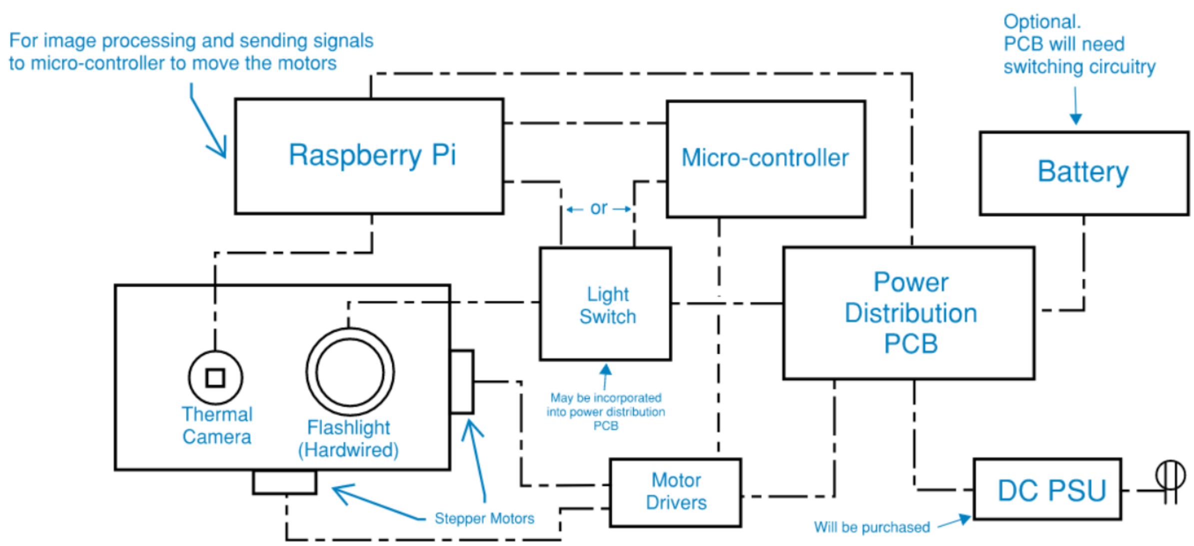

Figure 2: Design Concept Block Diagram

The main component will be a Raspberry Pi that is directly connected to the thermal camera and the micro-controller. As the Raspberry Pi processes the video feed from the camera, it will send signals to the controller in real time once a subject is detected, which will move the motors accordingly using the drivers that will be purchased. At the same time, either the Pi or the controller will send a signal to the light switch, which will be hardwired to the flashlight and allow power to go trough once it is turned on. This operation will continue until no heat signature is detected. In order to power all of these processes, a DC power supply will be acquired and plugged into a custom power distribution PCB that will be designed later on. That distribution board will supply the appropriate voltages to the Raspberry Pi, the motors, and the flashlight. Both the camera and micro-controller will be powered by the USB ports in the Raspberry Pi. If time allows it, we will also be implementing a backup power source in case of utility outages. This will be accomplished by equipping our system with a battery and designing the appropriate switching circuitry to automatically utilize the battery power when needed.

3.3 Technical Details

In this initial proposal, we carefully assessed four parameters to establish a foundational framework for the subsequent design considerations: motor precision, speed, and torque, as well as the total power consumption of the system.

To begin, when evaluating motor precision, we referred to the data sheet, which specifies a stepping angle for the motor of 1.8 degrees [7]. This implies that the motors can only move in increments of 1.8 degrees. Leveraging this information, we can derive an expression to quantify the level of precision with which the motors can orient the flashlight at a given distance:

$$L = \text{Distance from subject}$$

$$X = \text{Linear stepping distance}$$

$$\theta = \text{Stepping angle}$$

$$\tan\theta = \frac{X}{L}$$

Given that our performance goal is at a distance of L = 5 m, the linear stepping distance is:

$$X = L * \tan\theta = 0.156m$$

This essentially means that in the worst case scenario, the flashlight will be pointed with a precision of about 16 cm. Micro-stepping techniques will be examined to improve precision but are not yet an official part of the design. In order to evaluate the RPM requirement of the motor, one must consider the worst case in which the camera will need to rotate to track a subject that is very close to the camera and is moving from one bottom corner (as shown in Figure 1) to the other at S = 2.8 m/s. As a conservative approximation, one can assume that the required angle of rotation for this scenario is θ = 180 $^\circ$ since the subject is very close to the camera. With this information we perform the following calculation:

$$t = \frac{L}{S} = 1.79s \text{ (Time required to traverse length of the surveilled area)}$$

The RPM required is then:

$$\text{RPM} = \frac{\theta}{t} * \frac{60s}{360^\circ} = 16.8 \text{ RPM}$$

With such a relatively low RPM, we don't expect many problems when it comes to the speed of the motors and might even adjust our performance objectives to be higher. Now for the torque, the selected motor is rated for a holding torque of 3.5 kg * cm, which will comfortably accommodate the torque needed to rotate the camera and flashlight [7].

The final technical consideration that we are evaluating at this early stage of the project is the total power that will need to be supplied to the whole system. To determine this, the power draw of each major component was obtained. The Raspberry Pi 3 Model B will be our device of choice and it requires 5 V at 2.5 A to function [8]. The micro-controller will be powered by one of the Pi's USB 2.0 ports, so assuming that maximum power draw is achieved, it will consume about 2.5 Watts of power [9]. The selected motor is rated at a voltage of 3.4 V and 1.7 A and with a total of two, the power consumed is 11.56 W. This is expected to go higher as the actual voltage that will be applied to the motors will go well beyond its nameplate voltage for a faster response. Finally, the flashlight that is going to be used will draw about 6 W, conservatively (3 V at 2 A). This is all summarized in the following table and the total power is shown:

Component	**Power Draw [W]**
Micrcontroller	2.5
Raspberry Pi	12.5
Motors (2)	11.56
Flashlight	6
Total	32.56

Figure 3: Preliminary Load Calculation

The table above indicates that a power supply of more than 33 W will be required.

All of the results obtained in this section have yielded reasonable quantities that make for a feasible product with readily available parts.

3.4 Major Challenges

For this project, there will be many factors that will make the implementation of the system quite difficult. One of those factors includes the presence of multiple heat sources in the environment as it can introduce confusion for the tracking system. Ideally, it must be capable of distinguishing the desired target from other heat-emitting objects. Other external factors could include the speed of the tracked subject, size of the space being tracked, and even weather conditions. Other internal factors will include the image processing capabilities of our system, the speed and accuracy of the motors, as well as the integration of the software and hardware. Some of these will be addressed as part of the scope of the project while others (such as weather) will not be taken into account due to budget and time constraints.

3.5 Test Plan

Our test plan of the system will thoroughly occur at all phases of development. More specifically, testing will be performed once every sub-system is completed as well as during the development of that particular sub-system. This will provide reassurance that every component is working appropriately before they are all integrated together. It will also make it easier to debug the integration phase. Devising a testing plan for each sub-system is not possible yet, but for the final product, comprehensive test cases will be created in order to ensure that system is working properly. This will include putting subjects of different speeds, temperatures, and sizes in front of the camera to see how the system will react.

3.6 Resources and Equipment Required

Aside from all of the components that were listed so far, no other equipment needs to be purchased. All the development and testing can be done with our personal computers. The exception will be the enclosure for the entire system as it has not been decided whether it will be entirely 3D printed or assembled from pre-manufactured parts. Regardless of the choice, enough space in our budget will be left to handle this aspect.

3.7 Software Tools

The image analysis algorithm will be written in python, primarily utilizing the OpenCV library. The pySerial library will be used to interface between this software and the MSP432. Code composer studio will be used to write embedded C for the software running on the MSP432 microcontroller, which will drive the motors and light. In order to design and order the custom PCB, EasyEDA will be used.

4 External Considerations

4.1 Constraints

Usability We aim to make our automated searchlight usable by people of almost all ages and abilities, so the user interface seen by the consumer should be intuitive and easy to comprehend. We could accomplish this by adding multiple languages to the instructions and adding pictures to each of the components and software interfaces so that users of all languages and skill levels could enjoy the safety and security our system provides.

Part Availability The main materials needed for our system are the electrical components, printed circuit boards, cables, connectors, camera, gear housing, and power system. The system will integrate the primary components needed, such as the MSP 432 and the Raspberry Pi, which compose the brain of the system with their image processing and communication capabilities. As of the writing of this proposal, all of our selected parts are currently in stock. If this changes, we may need to substitute parts, but we do not foresee any difficulties acquiring our desired components.

4.2 Stakeholder Consideration

Economic and Cost The main economic constraint is represented by a $500 budget. During our component research, we realized the thermal camera we decided on cost almost half of our dedicated budget. Thanks to the University of Virginia's ECE department, we did not have to purchase the MSP 432 micro-controller. Besides this, the rest of the components do not pose major threats to a budget deficit as the flashlights, stepper motor, and housing components will all be within the $500 budget after the camera order is placed. Because this device is targeting more rural areas, we tried to pick components with our target audience in mind; however, with the time constraint, we decided to spend a larger portion of our budget on the camera.

Environmental Impact & Sustainability The main environmental impact is if the device itself is thrown away and the manufacturing of the components of this device. Recycling the device will be a challenge since it will comprise multiple parts that are unlikely to all be recyclable. Besides that, the system will be powered mostly through a power supply so there won't be much concern about batteries, and we are hoping to configure it to use a low-power design. This project presents a more sustainable design than prior work by implementing a low-power system designed for durability and long lifetime. If mechanical parts break down over time, replacements could be made to repair the device in the future making it mechanically repairable. For electrical parts, sensors could be replaced if any break, and the MSP or Raspberry Pi could be swapped out if there is electrical or physical damage to the board. We hope that, in terms of scalability for the future, the device may be upgraded to use solar power. As of now, it would cause a big strain on our time limit and cost.

Health and Safety Users should maintain routine checks to ensure that their device is working as intended. Our device will have image detecting capabilities to determine which entities caught in the motion sensor actually pose a threat to the property. This will allow the system to alert the user which entities they might want to pay attention to and if needed, take action against.

Ethical Issues Our main ethical concern involves the device running at all times unless the user has deactivated the security system. In that time it may capture innocent bystanders unfortunate enough to pass by, not wishing to be recorded. To try to minimize any potential controversy, we will encourage users to place a sign on their property referencing the camera and/or recording within a predefined area.

4.3 Standards and Regulations

For using a class 1 circuit, the standard is that the output power of the circuit does not exceed 30 V or 1000 volt-amps, and it can use a 120V power source from an outlet as preferred by OSHA standards [10].

The system will be coded in C++ for the algorithm and embedded programming available in this programming language. Our software will follow the Barr C/C++ coding standards to account for less bugs and for formal standards for ease of coding and communications [11].

With the use of electrical equipment and the MSP micro-controller, one of the standards involves an enclosure following one of the NEMA/IEC standards, which protects the user from an electrical shock along with protecting the electrical equipment from light, dust, and normal outside conditions [12].

5 Deliverables

By the end of the semester, our group will have produced a functioning prototype of an automated security spotlight. This device functions as an effective deterrent for any unwanted intruders within a preset area by illuminating potential invaders. This project will include several components such as the micro-controller, which will be used to serve as a pathway between the external components responsible for the outward-facing functions such as the motor drivers and the image-processing Raspberry Pi. To accomplish the image recognition, the thermal camera will have an output port that utilizes the images taken by the lens, saves them in digital format, and transmits them to the Raspberry Pi. The Raspberry Pi's image recognition software runs on an integrated CPU and GPU which analyzes various pictures of living and non-living objects before categorizing them in preparation for real-life test cases. Once the Raspberry Pi has identified an object as living, the unit sends signals to the micro-controller, which translates those signals into commands for the motor drivers to rotate the light source and illuminate the identified object. The flashlight will be controlled via an electronic switch such that it will turn on whenever the motors' start rotating, causing a beam of light to shine on the desired location according to the image recognition from the Raspberry Pi. Finally, our system will function off a DC power supply that will energize the power distribution PCB, which distributes the appropriate energy to the subsequent components. The PCB might also include a back-up battery in the event of power-outages. Both the DC PSU and battery will work to supply a constant voltage towards the power distribution PCB, which in turn allows current to flow into the subsequent ports associated with the various components such as the Raspberry Pi, light switch, and motor drivers, all of which depend on a steady voltage and current to operate within their appropriate energy consumption levels.

On the financial side, our group is expected to get close to the $500 budget on this project by the end of the semester. Approximately $200 will be spent on the thermal camera required for capturing images. The brains of the system, including the micro-controller and the Raspberry Pi, was obtained for free from the University of Virginia and will purchased for $50, respectively. The power supplies of the system such as the PCB, battery, and DC power supply will amount to a total of about $100 including design and assembly fees. The rotating motors, motor drivers, and wiring will be fairly inexpensive at $45 for all three components. Finally, the remaining $120 are left for a powerful enough light source to effectively illuminate objects at a distance of 5m along with any purchased or 3D-printed mounting components for the external components like the light source or camera.

6 Timeline

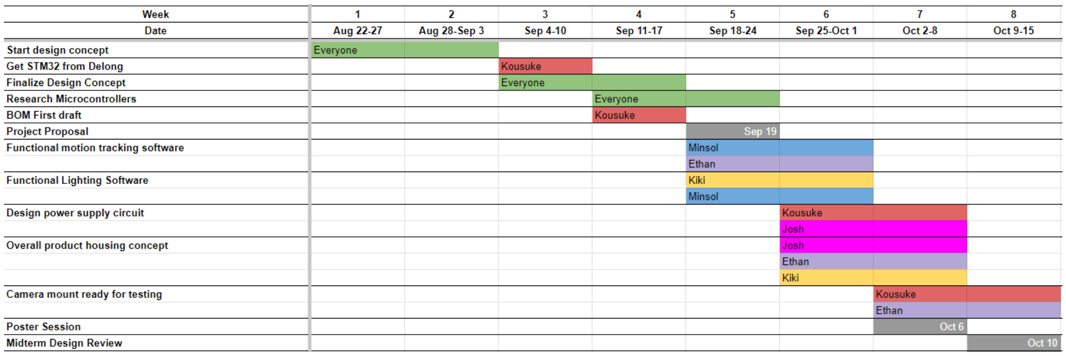

Figure 4: Gantt Chart Part 1

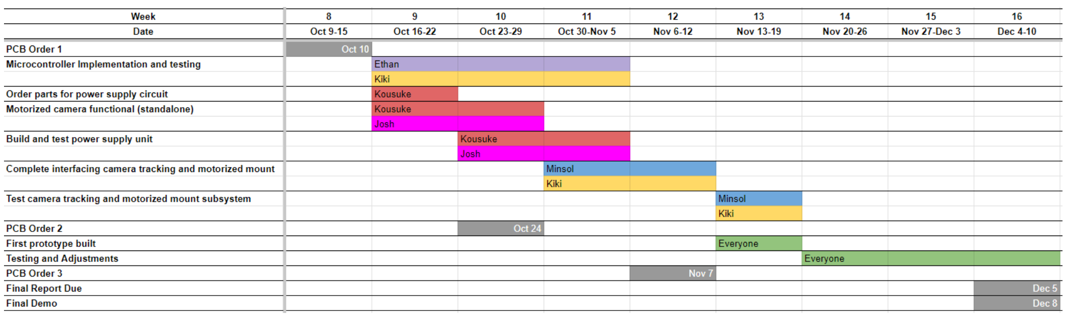

Figure 5: Gantt Chart Part 2

Our timeline for our project is 16 weeks long as pictured in our Gantt Chart above. We gave ourselves around 2 weeks each to do sequential tasks and paired people up for each task to ensure that if one person was unavailable, perhaps due to sickness, the other person would know what was going on and can fill in for any details that the rest of the team needed. For each subsystem, we provided some time to do testing as well so that the final prototype would go as smoothly as possible. We carefully budgeted our time to leave enough room at the end of the semester to have 3-4 weeks of building our prototype, thoroughly testing it, and making adjustments as needed before the final demo. We decided to start with most of the software because at the beginning we had not bought our parts yet to start working on the hardware. As we start putting in part orders we can work on more hardware specific tasks such as the camera mount setup, power supply, and PCB. Many of our tasks can be done in parallel as long as all the subsystems come together in the end so we focused more on making sure each team member's work was spread out across the semester. As far as team roles go, Josh and Kousuke will focus mostly on hardware. Josh's primary role will be structural hardware with a secondary in electrical hardware and vice versa for Kousuke. Ethan, Minsol, and Kiki will focus mostly on software. Ethan's primary role will be microcontroller software with a secondary in image processing software, Minsol's primary role will be image processing software with a secondary in motion control software, and Kiki's primary role will be the lighting software with a secondary in microcontroller software. Some members in the team have previous experience working with image processing and all members have experience developing PCBs and working with microcontrollers. However, the team as a whole must develop skills in integrating Raspberry Pis, engineering a 360 degree camera mount system potential made from 3D printed parts and, interfacing multiple subsystems to work as a cohesive machine.

7 Expectation

This project's success will be defined by the functionality and accuracy of the image processing software and flashlight's movement throughout the required areas. First, the flashlight must be able to shine everywhere within a predefined 5m area set within the software. That light must be able to illuminate areas of interest as well as follow any moving objects flagged by the image-processing software that traverse within the preset area. The reactivity and speed of the light must sufficiently track an object moving up to 5 miles per hour so as to capture the average human walking speed. In addition, the image processing must be robust enough such that the Raspberry Pi can differentiate inanimate objects such as leaves and rocks from objects of interest such as a passing human or animal. We will test our system's accuracy by running multiple pictures of test humans, animals, and inanimate objects through our image-recognizing software with an expected 10% margin of error as defined by the ambiguous or intentionally deceptive percentage of test cases being run through the Raspberry Pi.

Grade	Functionality	Accuracy
A	The system is able to move to and illuminate the entire preset area and can keep pace with all moving objects within acceptable bounds.	The system can near-perfectly distinguish between living and non-living objects and can rotate the motors with speed and precision according to the information
B	The system is able to move to and illuminate the entire preset area, but can mostly keep pace with slowly to moderately moving objects	The system can regularly distinguish between living and non-living objects better than random chance and can rotate the motors according to the information
C	The system is able to move to and illuminate the entire preset area, but can not keep pace with moving objects	The system can occasionally distinguish between living and non-living objects better than random chance and can rotate the motors according to the information
D	The system is able to slightly move to and illuminate, but not the entire preset area	The system can occasionally distinguish between living and non-living objects better than random chance, yet can not rely information to the motors
F	The system is unable to move to or illuminate any of the preset area	The system is unable to distinguish between living and non-living objects

Figure 6: Grading Criteria for Automated Search Light

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