RASPBERRY PI GAME CAMERA

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Abstract— **This document presents the design and implementation of a game camera using a Raspberry Pi 4 and the C programming language. The primary objective was to explore the feasibility of independently constructing a motion detection-based camera system that operates on solar power under both night- and daytime lighting conditions. Nighttime images improved significantly after hardware optimization to the extent that silhouettes were discernible at 2-3 feet, though complete darkness remained a challenge. The results demonstrate the viability of the system as a proof-of-concept, while also providing valuable insights for future extensions and modifications.**

I. INTRODUCTION

In recent years, the use of motion-based cameras for a variety of purposes has grown exponentially. Use cases include doorbell cameras, baby monitors, security cameras, and wildlife cameras. Wildlife cameras are particularly popular among hunters, researchers, and wildlife enthusiasts. These devices play a newfound and crucial role in monitoring wildlife activities, providing invaluable insights into animal behavior, population dynamics, habitat use, and migration patterns. They offer unprecedented access to wildlife, fostering our connection to the natural world.

While solar-powered off-the-shelf game cameras are readily available, the goal here was to leverage the flexibility of the Raspberry Pi platform and provide a way for hobbyists to build their own.

This paper presents the design and implementation of a custom game camera using a Raspberry Pi 4 and the C programming language. The primary objective was to achieve a proof-of-concept and to gain hands-on experience in designing, producing, and programming embedded systems. Secondary objectives include maintaining power and memory efficiency.

By combining open-source software, the computational power and flexibility of the Raspberry Pi 4, and cost-effective components, this project offers a practical alternative to off-the-shelf game cameras. The design, implementation, and performance of the camera system are discussed alongside its limitations and potential enhancements.

II. DESIGN

A. Overview

The proposed device is intended to capture images or video in a remote location and store the media locally. The device would be powered by a battery connected to a solar panel. The user would interact with the device by utilizing a mobile hotspot and connecting to the Raspberry Pi via SSH to retrieve the stored media. Alternatively, users could power down the camera, retrieve the SD card, and use an SD card reader to transfer the media to a computer. This section details the hardware and software components necessary for implementing the design.

B. Hardware

The system was initially planned to operate on a Raspberry Pi Zero due to its compact size and low power consumption. However, the Raspberry Pi 4 was ultimately chosen for its greater computational power, better connectivity options, and the need to expedite system configuration given project time constraints.

The hardware design prioritizes sustainability and functionality, incorporating the following components:

- **Power Supply**: A 10W 12V solar panel and a 10,000 mAh battery were selected to ensure reliable power in remote locations.
- **Sensors and Imaging**: A Passive Infrared Sensor (PIR) detects motion and triggers a Raspberry Pi camera module to capture images or videos. Two infrared (IR) LEDs enable nighttime operation, while a photocell receptor optimizes energy usage by deactivating the LEDs during daylight.
- **Supporting Components**: Additional components include a 2N2222 transistor for efficient power management, resistors for circuit stability, jumper cables, a breadboard, and connectors to complete the assembly.

This combination of components ensures energy efficiency and robust functionality in both daytime and nighttime conditions.

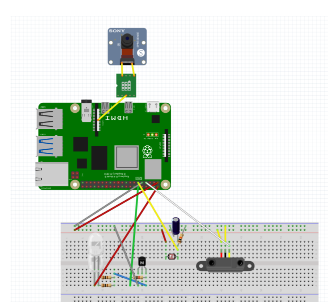

Fig. 1. Wiring Diagram

C. Software

The software for this system was designed exclusively in C to maximize precise control over memory man-

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agement and hardware interaction. The design prioritizes lightweight implementation by minimizing dependency on external libraries, relying only on essential modules such as `pigpio.h` for GPIO control and `libcamera` for camera interaction.

The program is structured using the Model View Controller (MVC) design pattern:

- **Model**: Manages data and hardware state, such as tracking motion events and controlling GPIO pins.
- **View**: Provides terminal-based feedback for debugging, with future potential for custom display integration.
- **Controller**: Manages system events, such as motion detection, and coordinates actions by delegating tasks to the model and updating the view.

The MVC pattern allowed for simplicity in debugging as well as readability. It also provides modularity for future upgrades.

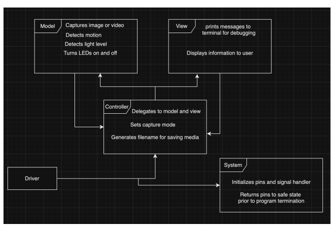

Fig. 2. MVC UML Diagram

Libraries such as `pigpio.h` for GPIO control, `libcamera` for camera interaction, and standard C libraries like `stdio.h` and `stdlib.h` were utilized. These libraries provided the necessary functionality while maintaining a lightweight and efficient application suitable for an embedded system.

III. BUILD PROCESS

The build process focused on the assembly and configuration of the device. Initially, a Raspberry Pi Zero WH was considered but replaced with a Raspberry Pi 4 for practical reasons discussed earlier. The Raspberry Pi 4 was configured with the Lite version of Raspberry Pi OS, allowing for efficient resource usage. Hardware components, including the camera module, PIR sensor, and power system, were installed incrementally, with each component tested individually to confirm functionality before integration.

One of the challenges of the build process was the physical layout of all the components. Ideally, the PIR sensor, camera module, IR LEDs, and photocell would all be outwardly facing on the same breadboard. This arrangement would facilitate testing and real-world use. However, this setup was complicated by the physical constraints of a GPIO data cable, Pi cobbler, and breadboard instead of soldering the components directly. Soldering could have provided a more compact and durable solution but would have left more opportunities for error, and the lack of prior soldering experience made this approach unviable.

Energy efficiency and nighttime performance were addressed through iterative testing, as detailed in the Experimentation section.

IV. EXPERIMENTATION

The experimentation phase was critical for validating the system's design and functionality. Testing began with standalone evaluations of individual components before progressing to integrated system tests. This approach ensured that any issues could be identified and resolved incrementally, minimizing complications during full system integration.

Camera Testing

The initial focus was on evaluating the Raspberry Pi camera's ability to capture images and videos under various lighting conditions. Using system calls to the `libcamera` library, full-light tests produced clear and detailed images, confirming the camera module's baseline functionality. Nighttime tests, however, revealed significant challenges. With only a single IR LED, the captured images were dim and largely illegible. Adding a second IR LED improved the brightness and clarity but did not fully resolve concerns.

To address these issues, pull-up resistor values in the IR LED circuit were adjusted. Extensive evaluation of the power specifications of the IR LEDs, the transistor, and the capabilities of the Raspberry Pi 4 informed these adjustments. Ohm's law was used to calculate resistor values that would maintain safe resistance while optimizing illumination. A photocell was integrated to deactivate IR LEDs during daylight, improving overall energy efficiency. A 220-ohm resistor, while energy efficient, did not provide sufficient illumination. Replacing it with a 100-ohm resistor significantly improved the clarity of nighttime photographs. Despite these improvements, the power constraints of the system limited further enhancements, and complete nighttime coverage remained suboptimal.

Motion Detection Testing

The PIR sensor was tested for motion detection accuracy by simulating movement at varying distances and angles. Under controlled conditions, the sensor reliably detected motion and triggered the camera module to capture images. The system demonstrated a low false-positive rate during these tests, indicating robustness in detecting genuine motion events. Integration tests confirmed that the PIR sensor and camera module worked seamlessly together, capturing and storing media upon motion detection.

Integrated System Testing

End-to-end testing validated the functionality of the fully assembled system. These tests involved simulating real-world conditions, such as alternating periods of motion and inactivity, and evaluating the system's response. During daytime scenarios, the system performed reliably, capturing clear images upon motion detection. At night, while the improved IR LED configuration enhanced performance, the illumination was still insufficient in complete darkness.

Energy efficiency was also assessed during these tests. The addition of a photocell to deactivate IR LEDs during daylight reduced unnecessary power consumption. This feature, combined with careful resistor value optimization, was designed to improve the system's operational efficiency. However, the operational lifespan on a single battery charge has not yet been tested, leaving long-term power endurance as an area for future evaluation.

V. RESULTS

The results of the experiments confirmed the system's viability as a motion-activated game camera, with both strengths and limitations. During daytime operation, the camera consistently captured high-quality images triggered by motion. This performance aligned well with the project's objectives and demonstrated the reliability of the integrated system.

Fig. 3. Full Light result

Nighttime operation showed significant improvement following iterative adjustments to the IR LED configuration and resistor values. Before the addition of a second IR LED and the use of 100-ohm resistors, nighttime images were nearly completely dark, with no discernible features visible. After implementing these changes, test images captured from a distance of 2-3 feet showed a discernible silhouette of a face. This qualitative improvement indicates a significant enhancement in brightness and visibility, though exact luminance measurements were not recorded. However, the system's reliance on a limited power source constrained further improvements, and complete illumination in total darkness remained a challenge.

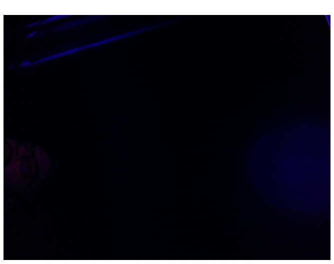

Fig. 4. Initial result in full dark

Fig. 5. Result with additional IR LED and resistor modification

The PIR sensor performed reliably, accurately detecting motion and triggering the camera module without significant false positives. The inclusion of a photocell enhanced energy efficiency by ensuring that the IR LEDs were only active when necessary, optimizing power usage during daylight hours.

Despite these successes, the system's limitations were evident. Power constraints prevented the addition of more IR LEDs or further reductions in resistor values, both of which could improve nighttime performance. The lack of formal testing for long-term solar-powered operation leaves room for future investigation to ensure sustained functionality in outdoor conditions. Camera response time was sufficient for testing purposes. Data retrieval was easy when an SSH connection was made. However, the inability to SSH into the device through a phone's hotspot left a suboptimal solution for data retrieval, requiring disconnection of power and removal of the SD card. This risks SD card read/write errors. Adding button toggles to power down the device would address this limitation.

These findings demonstrate the potential of the system as a proof-of-concept while highlighting clear areas for improvement in subsequent iterations.

VI. CONCLUSION AND FUTURE WORK

This project successfully delivered a proof-of-concept for a motion-activated game camera powered by solar energy. This proof-of-concept demonstrates the potential for hobbyists to create custom wildlife cameras with sustainable energy solutions.

While the prototype achieved its primary objectives, several limitations highlight areas for future work. Enhancing nighttime illumination with additional IR LEDs or exploring more efficient lighting solutions is a critical area for improvement. Future testing could involve measuring light levels in lux to quantify improvements more precisely.

A cursory look at commercially available game cameras identifies the number of IR LEDs to be increased to the range of 10–20 or more. Some devices also appear to incorporate green LEDs, theoretically for low-light conditions such as dawn and dusk, which would be an additional area of potential improvements. The integration of an ADC for refined light sensing could further optimize energy management.

Long-term solar power performance is worthy of further testing and evaluation. Creating multiple prototypes utilizing varied solar panels as well as battery capacities could provide valuable information on the optimal configuration.

User experience enhancements, such as a dedicated interface for toggling between modes and improved media retrieval options, are also recommended. One area of investigation is the feasibility of local Bluetooth connectivity for file transfer. Finally, designing a durable, weatherproof casing would ensure the device's suitability for prolonged outdoor use, enabling its deployment in real-world wildlife monitoring scenarios.

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