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MothCam: Automated Photography of Nocturnal Lepidoptera for Urban Citizen Science

Rationale

Moths, a part of the Lepidoptera genus, are among the most important but underappreciated pollinators, and are often overlooked (Walton et al., 2020). Unlike bees, which are active during the day, moths primarily operate at night, contributing to the pollination of plants that bloom outside of daylight hours. Recent studies show that moths, such as the large yellow underwing, are significant pollinators of key agricultural crops like red clover, with researchers finding that up to 34% of pollination in red clover was performed by moths (Kuta, 2022). Moths are thought to be responsible for pollinating hundreds of other less-studied species, particularly nocturnal blooms, and likely play a much larger role in global ecosystems than previously recognized (Why Moths Matter, n.d.).

In addition to their critical pollination services, moths are also a fundamental part of the food chain. Their larvae (caterpillars) are vital for the survival of many bird species. For example, blue tit chicks, a common species in Europe, rely on moth caterpillars for nutrition, with an estimated 35 billion caterpillars needed annually to sustain these birds (Why Moths Matter, n.d.) In fact, 60% of bird species could face catastrophic population declines if moth populations were to plummet (Why Moths Matter, n.d.)

The decline of moth populations globally has been linked to habitat loss, pesticides, light pollution, and climate change. These factors pose serious risks not only to moths but to the broader ecosystems they support (Why Moths Matter, n.d.) Protecting and preserving moth populations is therefore crucial, and one of the first steps toward this goal is accurate data collection.

Data collection provides insights into population sizes, behavioral patterns, and environmental interactions. For moths, traditional data collection involves manually photographing them after they are attracted to floodlights and white sheets. However, this method is labor-intensive, prone to human error, and excludes many moth species not drawn to such lighting. This process is begging for automation to reduce labor, improve the breadth of species captured, and minimize human error. Automation will allow researchers to gather more comprehensive data on moth activity, such as population sizes, nocturnal behavior patterns, and seasonal changes, enabling more informed conservation efforts to protect these essential creatures.

New technologies, like computer vision-based light traps and deep learning algorithms, have already shown promise for an automatic moth trap. These systems can automatically attract, track, and classify moth species based on captured images. For example, a recent study demonstrated that a deep learning model successfully classified over 2,000 labeled moth images with high accuracy, capturing data over long periods without requiring constant human supervision (Bjerge et al., 2021). This approach not only reduces labor but also eliminates errors that arise from manual counting and species identification.

However, a low-cost and rapidly deployable automatic moth camera is still lacking. A device with those features would allow for a whole network of moth monitors, mounted in rural, suburban, and urban areas by homeowners. This will open up more possibilities in the moth monitoring world.

Engineering Goal

I plan to develop an easily deployable, small, moth monitoring package that anyone can set up and use. In addition to the following design criteria, I would like for the device to be affordable enough that it can be deployed in a wide range of scenarios.

The first goal of the experiment is to use a standard E26/E27 light socket to provide 120 VAC for the device. This will not only allow for easy mounting, but also for easy power sourcing. The power will be stepped down to 3.3 VDC for use by the camera sensor and the microcontroller and will also be stepped down to power the LEDs with a constant current power controller.

The second goal of the experiment is to develop an effective lighting array to attract the moths. Brehm (2017) showed that the most effective wavelengths for the attraction of moths are 368 nm (ultraviolet), 450 nm (blue), 530 nm (green), and 550 nm (cool white). The best configuration for these are 4 UV LEDs, 2 blue, 1 green, and one white. The LEDs used in this experiment will be 3 watts and be powered with ~350 mA, ~3 VDC each (dependent on the forward voltage of the diode).

The third goal of the experiment is to develop an automatic moth photography system to capture details of the moth when in close proximity to the device. This will hopefully be achieved using an ESP32 Cam and an OV5640 camera module. If proven successful, a custom Printed Circuit Board (PCB) will be developed mounting the bare chip for cost savings.

The fourth and final goal of the experiment is to develop a system to send all the photos over Wi-Fi to a main server where they will be stored and made available to researchers via a web page or uploaded to a pre-existing webpage. If time allows, an Artificial Intelligence (AI) platform will be utilized for automatic detection of the species of the moth.

Prototype Development

Safety

A potential risk in this experiment is the use of high-voltage AC. Proper precautions will be used such as covering all exposed live wires with heat shrink or electrical tape and following proper grounding etiquette. Additionally, high temperature tools like soldering irons will be used, so proper eye protection (goggles) and ventilation (fume extractor) will be utilized.

Materials & Equipment

Most materials are sourced via Amazon to reduce prototyping costs.

LED

- 4x UVA LEDs - 370 nm, 3 watt
- 2x blue LEDs - 440 nm, 3 watt
- 1x green LEDs - 530 nm, 3 watt
- 1x cool white LED, 3 watt
- LED mounting PCBs for blue and white LEDs
- 350 mA constant current LED driver

Other Electronics

- ESP32-CAM
- OV5640 camera module
- IRFZ44N power MOSFET
- 120 VAC to 3.3 VDC converter
- E26 male socket
- Generic LDR sensor
- Generic ¼ watt assortment of resistors for LDR and MOSFET
- Generic wires
- Generic perfboard

Hardware

- Clear acrylic for screen cover
- Generic Aluminum for LED heatsink
- 3D prints
- Assortment of M3 screws

Design & Construction

Since the design of the device is ever-changing, the design and construction of the device is not set in stone. Rather, it will be iterated upon and changed throughout the engineering cycle and process. However, preliminary insights into the design and construction can be provided.

The first step in the production of the device is development of the electronics. As previously stated, the electronics will include an ESP32-CAM PCB and an OV5640 camera module along with some power electronics. First, the power for the device will be obtained from a male E26/E27 socket. The hot and neutral leads of the socket will lead to a generic 120 VAC to 3.3 VDC step-down transformer, soldered to the input terminals. Soldered to the output of the step-down converter will be leads going to the microcontroller and camera. Again soldered to the 120 VAC leads will be a constant current supply for powering the LEDs. The LEDs will be soldered together in series. Using the N-channel power MOSFET, the LEDs can switch on and off. The MOSFET will be placed in between the last LED and ground. Attached to the gate of the MOSFET will be a 10 kilo Ohm pulldown resistor. Between the gate and one of the microcontroller's general purpose input output pins (GPIO) will be a 10 Ohm resistor for controlling the state of the MOSFET. The OV5640 camera module will simply slide into the builtin camera connector slot on the ESP32-CAM module. For prototyping, this design will be made on a perfboard for ease of mounting in the case.

Next, this design will be integrated into a hybrid 3D-printed enclosure made with PolyLactic Acid (PLA) and laser cut clear acrylic front panel. The enclosure will be printed like a box but with the top missing. This is where the electronics will be placed. The perfboard containing the power electronics and the camera will be mounted facing upwards, and the 4 UV LEDs will be placed on the left and the 2 blue, green, and white LEDs on the right. The power will be coming from a hole in the side of the case adjacent to the perfboard via the E26/E27 connector. The acrylic front panel will then be bolted down on top of the box with an o-ring in between for weather proofness. The whole box will be rotated 90 degrees so that the E26/E27 is facing the top. Next, dowels will be placed in small exterior holes at the bottom, running perpendicular to the front panel. These dowels will act as rods to hold the camera stage. This is the place the moths will land and be photographed.

The final step in the development process is to design the way for the images to be captured by the camera module and then transmitted to the server. Since we are using an ESP32 module, we can use the Arduino framework (based on C/C++) for programming the camera. We can use multiple open source libraries that have already been developed to take the photos. The photos will be taken as often as possible but not too often to lessen the strain on the device. The ESP32 will transmit the photos over Wi-Fi using websockets to a Python server using a modified bit of code. Once transmitted to the server, a Python script using OpenCV will create a mask on the image, determining if there is a difference in the camera stage. If confirmed, then the photo will be stored for further classification. If not, it will subsequently be deleted. Furthermore, depending on functionality, either a Light-Dependent Resistor (LDR) or a local sunset system will be employed to know when to turn on the LEDs and to start the stream. Using the bidirectional Wi-Fi capabilities, the device can get the local sunset in its area and calculate when it needs to turn on the LEDs, saving power during the day. The LDR can measure the amount of light and can also be helpful in determining when the LEDs are necessary.

Prototype Testing

Since this device is intended to photograph moths, it will need to be exposed to the outdoors for over a night to collect all necessary information and data. The testing of the prototype will be carried out in a systematic manner, addressing each functional goal to ensure the device operates as intended while adhering to the design criteria.

The first stage of testing will focus on the power supply and ease of deployment. We will connect the prototype to a standard E26/E27 light socket, which provides 120 VAC, and confirm that the voltage is stepped down to 3.3 VDC for the camera sensor and microcontroller. We will also confirm that the constant current power supply is functioning properly for the LEDs. Using multimeters, we will measure the voltage and current at different points in the circuit to ensure that the power conversion is stable and within the required ranges. Additionally, we will assess the ease of mounting the device in various locations to verify that the design allows for quick and simple setup, a critical aspect of the deployment process.

Next, we will test the effectiveness of the lighting array in attracting moths. Since moths are particularly responsive to wavelengths around 368 nm (ultraviolet), 450 nm (blue), 530 nm (green), and 550 nm (cool white). We will configure the array with 4 UV LEDs, 2 blue, 1 green, and 1 white, each powered at ~350 mA and ~3 VDC. Using a simple spectroscope, we will verify the LEDs are transmitting the correct wavelengths. Field tests will then be conducted in various environments, where we will record moth activity at different distances and conditions to gauge the lighting array's attraction effectiveness. This step is crucial to ensure the device can attract a diverse range of moth species in natural settings.

The third phase of testing will focus on the automatic photography system. The ESP32 Cam, combined with the OV5640 camera module, will be tested for its ability to capture high-resolution images of moths in close proximity to the device. We will evaluate the camera's performance in low-light conditions and its ability to trigger quickly when moths approach. Key measurements will include image clarity, resolution, and motion capture accuracy. This will help us confirm whether the device can produce detailed, usable images for species identification. The camera's response time, from moth detection to image capture, will also be measured to ensure that the system is responsive enough to capture fast-moving subjects.

Finally, the data transmission system will be tested to ensure that all images are sent via Wi-Fi to a central server, where they can be accessed by researchers through a web interface. We will evaluate the reliability and range of the data transfer, monitoring for any delays or failures in uploading images. In addition, the ease of access to the data via the server will be assessed, ensuring that the system is user-friendly for researchers who will analyze the images. If time permits, we will explore the integration of an AI platform for automatic species identification, enhancing the data processing capabilities of the system.

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