Pit Viper-Inspired Integration of Infrared and Visual Sensing

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***Abstract*—Pit vipers leverage both infrared (IR) and vision for hunting. Each sensing modality can function independently but operate more effectively together, motivating the hypothesis that combining and IR and vision will out-perform single-sensing approaches in navigation and prey detection. To test this underlying hypothesis, a robot with dual-sensing capabilities has been designed to integrate information from a Adafruit MLX90640 IR Thermal Camera Breakout - 55 Degree and Raspberry Pi Camera Module 2 and steer the robot accurately towards a target. Thermal sensing performed the best, having the shortest time to reach (TTR) to the target, and the lowest heading angle variance across trials. Visual sensing performed the worst, having the largest variance in heading angles and the longest TTR. Dual sensing had the least variance in heading angle, but did not outperform thermal sensing alone in terms of TTR. The results of this project highlight the integral role IR sensing plays in target tracking accurately during predator-prey interactions.**

***Index Terms*—Infrared Vision, Camera Vision, Pit Vipers.**

I. Introduction

Pit Vipers are ferocious predators that are able to accurately strike their prey, even in darkness. These animals leverage infrared vision, through pit organs rich in heat-sensitive nerve fibers, while hunting to track the radiation emitted by their target. They also use many visual cues during hunting, particularly for navigation and landmark recognition. Both sensing modalities are integral in achieving high predatory performance.

In this report, two sensing modalities, infrared and visual sensing, are integrated to navigate towards a target or prey. In order to implement this, the authors built a mechanical platform that can be steered through differential drive. A Raspberry Pi Camera Module 2 is used to collect visual data, while a Adafruit MLX90640 IR Thermal Camera Breakout - 55 Degree is used to collect thermal data. This data is processed to identify the distance from target and the desired heading angle to steer towards the target.

In this report, the main contributions of the project are outlined as follows:

- Designing a snake-inspired mechanical platform for IR and vision based steering
- Developing an algorithm to process thermal images and identify the centroid of the heat map
- Developing an algorithm to process visual images and identify the centroid of the target and its' distance relative to the robot

II. Background

A. Infrared (IR) vision in rattlesnakes

Rattlesnakes can accurately strike prey, even in darkness by sensing infrared radiation emitted by their prey [1] . Pit organs act as the "eyes" of the rattlesnake, which are rich in heat-sensitive nerve fibers that connect to the brain [2]. These pit organs are used to identify prey, and allow the animal to track and locate thermal targets, even when blindfolded [3]. While pit organs are important in finding prey, it was found that rattlesnakes do not rely on their pit organs during simple navigation. A study by Schraft and Clark found that snakes primarily use visual cues to orient themselves (e.g. identifying bushes and structures) and navigate in the darkness [4], rather than infrared cues. Rattlesnakes in general, are believed to only use infrared sensing in certain contexts, particularly locating prey while hunting [4].

B. Integration of IR and vision sensing

In absence of both visual and infrared sensing, predatory performance diminishes significantly. However, it has been shown that these sensory systems can still achieve high performance (75%) when either one of eye vision or pit organs were occluded [5], [6] . The results of these studies imply that rattlesnakes can effectively switch sensing modalities and still achieve high predatory performance, but ultimately integrate both modalities of sensing for optimal navigation and hunting.

III. Hypotheses

The main biological principle the authors will be exploring in this paper is the integration of dual perception and sensing in rattlesnakes which is used to achieve high performance during predatory hunting. This is further detailed in the following three cases below:

1) Navigation and prey/target detection using two sensing modalities will achieve higher performance than just one modality
2) It is still possible to navigate and locate a prey with just IR sensing (but performance will be reduced)
3) It is still possible to navigate and locate a prey with just vision (but performance will be reduced)

IV. METHODS

In order to test the following hypotheses, the authors designed and built a robotic pit viper. The robotic pit viber was designed to enable steering through differential drive. The control logic is programmed onto a Raspberry Pi 4 which was powered externally (the robot remained tethered during the experiments).

A. Mechanical Platform

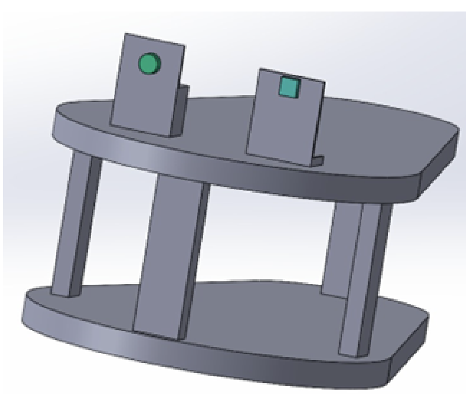
The authors' main goal from a mechanical perspective is to make room for all the electronic parts, including the Raspberry Pi, breadboard, camera, thermal sensors, motors, batteries, wiring, etc. To ensure that motors and sensors don't wobble while operating, the mechanical housing should also have specific design elements.

1) Concept generation: Our authors developed the design below during preliminary conversations, with the electronic components on the top and bottom base plates intended to be made of acrylic. The authors have also decided to use the trike's motorized front wheels and driven rear wheels for propulsion. For the robot's turning, the differential drive concept was selected.

2) Design iterations: The initial design, shown in Figure 1 was CAD model that replicated the idea was created by designers. A table-like framework was all that was originally intended to house sensors at the top and other electrical components that would be packaged below the base.

The final design, in Figure 2 is a snake-head structure was created following multiple forums, as seen below. There is adequate room for sensors at the top that resemble the snake's eyes thanks to this snake-inspired design. Both housings' front sections are sufficiently shaped to avoid obstructing the sensor's field of vision.

Fig. 1: Initial Design



3) Manufacturing failures: The body and wheels were created by the writers using 3D printing technology. The outputs were not what was anticipated because of the design's robustness. The body designs were divided into multiple pieces and intended to be joined using the projections and holes method, based on the lessons learned about designing quickly for manufacturing (3D printing). Following a difficult post-printing procedure that resulted in assembly features breaking, the bodies were assembled using Velcro and glue. Velcro is specifically employed to make assembly/disassembly feasible in the event that electronics need to be updated.

Fig. 2: Final Design

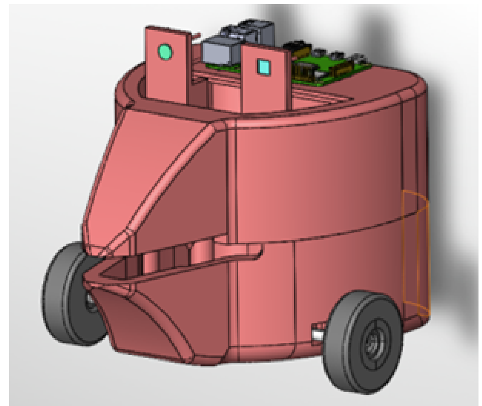


Fig. 3: Manufacturing failures

B. Sensing modalities

1) Vision: For visual sensing, the authors used a Raspberry Pi Camera Module 2 to gather visual images of the environment. As a image recognition module would've been beyond the timing constraints of the class, April Tags [1] were used as a low power proxy for object recognition, that provides useful information about the robot's location relative the April Tag.

For each image, it first checks if an April Tag was detected. If so, the pixel coordinates of the centroid of the April Tag is calculated. From there the heading angle and distance to the target are calculated with the following equations:

$$\text{Distance from target} = \frac{\text{tag\_size\_cm} \times \text{frame\_width\_pixel}}{\text{tag\_size\_pixel}}$$

$$\text{Heading angle to target} = \text{delta\_y} \times \text{angle\_per\_pixel}$$

The tag_size_cm is the true size of the April Tag in cm. During testing, April Tags of 3 cm were used.

[1] https://april.eecs.umich.edu/software/apriltag

Fig. 4: Sample of visual data - annotated

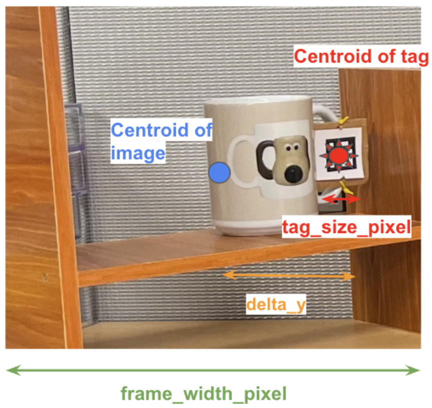
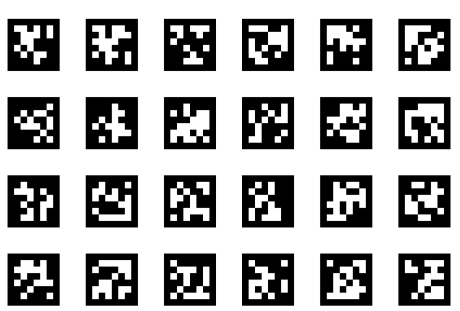


Fig. 5: April tags

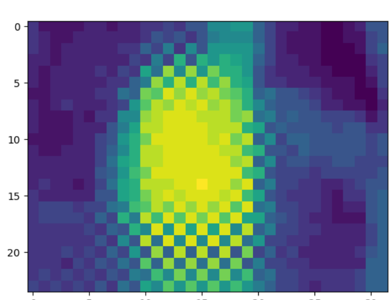


2) Thermal: For thermal sensing the Adafruit MLX90640 IR Thermal Camera Breakout - 55 Degree provides a thermal image as shown in Figure 6.

For each thermal image, a binary mask is applied to identify areas above the temperature threshold (>35). The `center_of_mass` function from `scipy.ndimage` is then used to calculate the thermal centroid.

The heading angle is calculated with the same formula used for visual sensing. Note that delta_y is calculated as the pixel distance in y from the center of the image to the thermal centroid.

Fig. 6: Sample of thermal data



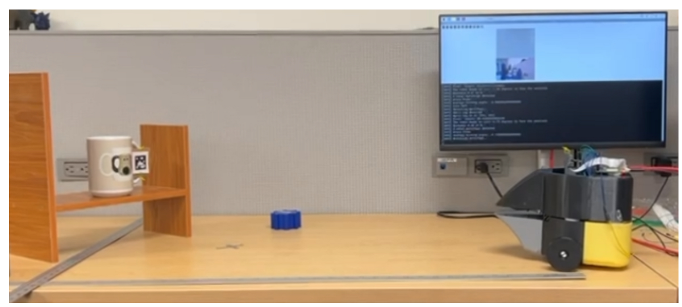
3) Integration: To integrate these two sensing modalities, the desired heading angles were averaged from each sensing modality. The authors note this is a rudimentary implementation of sensing integration, and further implementations could consider uncertainty of data measurements to weigh the heading angles accordingly.

To steer the robot, the authors implemented a simple bang-bang controller: when the desired heading angle is small ($|\theta| < 1°$), the robot goes straight; otherwise the robot turns towards the target until heading angle is small.

V. Testing Setup

To perform the experiments, the authors tethered the robotic platform to a power supply, monitor, and keyboard on a test bench. Figure 7 shows the configuration for all experiments, with the robot and target being separated by approximately 1m.

Fig. 7: Experimental test bench. On the left is the thermal source with an April Tag attached. On the right is the robotic platform before starting. The monitor displays the feedback from both thermal and visual sensors.



The authors performed five trials for three different experimental configurations: (1) visual sensing only; (2) thermal sensing only; (3) both visual and thermal sensing. During each trial, the calculated "heading angle" from the two sensing modalities were recorded, along with the timestamp associated with each data point.

Accuracy during a trial was evaluated by the time to reach (TTR) the goal (denoted by a taped 'X' on the test bench) and the variance of the heading angle over time. A shorter TTR would suggest higher accuracy, as well as low variance of the heading angle during a trial.

VI. Results

High overall accuracy was observed when integrating thermal and visual sensing as opposed to using either exclusively. Because both thermal and visual images were being captured regardless of trial type, the frame rate of all trials was limited to $\approx 2\text{Hz}$.

Visual sensing trials, seen in Figure 8, were observed to have the longest TTR and the largest heading angle variance for each trial. Each trial varied by approximately $20°$ on average between maximum and minimum heading angle values.

Thermal sensing trials, seen in Figure 9, had the shortest TTR and the lowest heading angle variance for each trial, varying approximately $15°$ per trial. Although the resolution of the thermal sensor was lower than that of the visual, it permitted the system to remain more consistent with respect to its heading angle.

Dual sensing trials, shown in Figure 10, showed the least variance in heading angle, but not as short of a TTR as thermal sensing alone. When integrating both sensing modalities, an obvious calibration error was observed in that both sensors read different initial heading angles, even though they were oriented identically.

Fig. 8: Results for visual sensing trials.

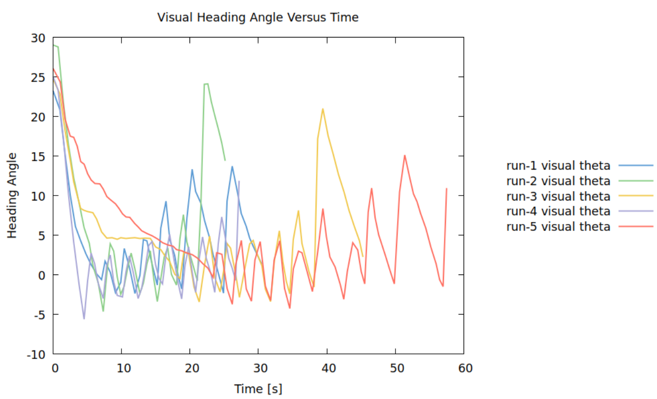
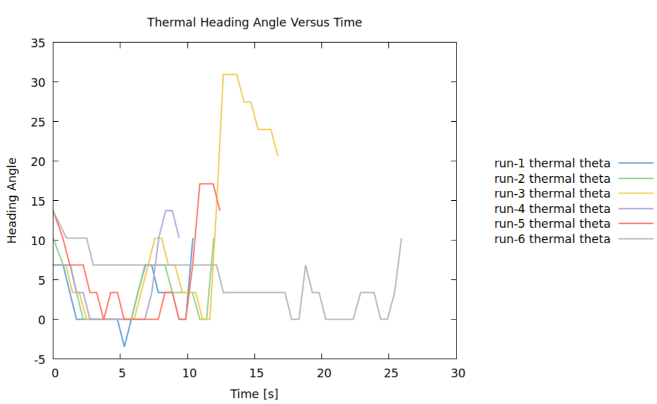


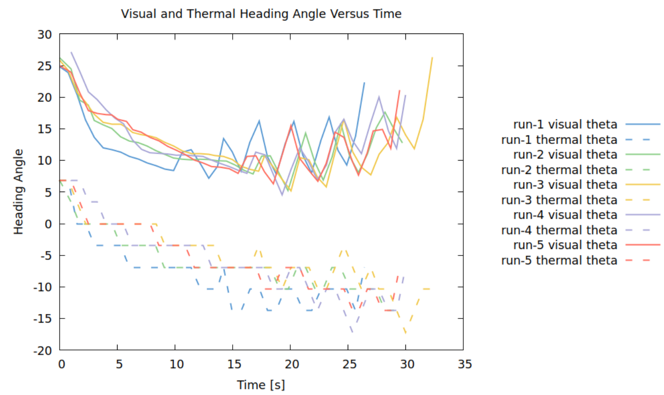
Fig. 9: Results for thermal sensing trials.



VII. Discussion and Future Work

Thermal sensing was more accurate and quick to detect and steer towards a target, which is similar to how pit vipers rely primarily on IR sensing during hunting to accurately strike prey. Dual sensing performed worse than IR alone with respect to TTR, which was contrary to the initial hypothesis (that dual-sensing would outperform single sensing modalities); however, dual sensing outperformed both individual modes of sensing with respect to heading angle variance. The observed increase

Fig. 10: Results for dual sensing trials.



in stability can be attributed to the steering algorithm averaging the thermal and visual centroids. The longer TTR for dual sensing could be a limitation of how the sensor data was integrated (averaging angles). A more sophisticated way to fuse information (e.g. weighing data by uncertainty) could potentially yield more accurate results.

In this project, the authors developed a snake-inspired mechanical platform to IR and vision based steering and developed an algorithm to process thermal and visual images and identifying the desired heading angle to steer towards. The results support that IR sensing plays an integral role in prey tracking during hunting.

References

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