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LOW-COST MULTI-SENSOR PLATFORM FOR MONITORING INSECT BEHAVIORAL RESPONSES TO ENVIRONMENTAL CHANGE: A CASE STUDY IN ANTS

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Insect foraging behaviour is influenced by various environmental factors; however, continuous monitoring under natural conditions remains technically and financially challenging. In this study, we present a cost-effective, autonomous multi-sensor monitoring system developed to investigate the foraging behaviour of a ground-dwelling ant species in relation to temperature, humidity, and light intensity. Leveraging a low-cost ESP32 microcontroller and a MATLAB-based optical flow computer vision algorithm, the system enables continuous monitoring and analysis of ant activity (ingress and egress). A comprehensive dataset was collected every 15 minutes from 23 to 29 August 2024, including environmental parameters (temperature, relative humidity, and light intensity) and corresponding ant ingress and egress counts. During the observation period, a 5-minute video feed for each time interval of 15 minutes was captured. This, paired with the environmental parameter logging system, captured data over a total duration of 168 hours (7 days), resulting in 672 discrete 15-minute intervals. Nearly 709 Carpenter ants (Family Formicidae) were observed moving either in or out of the monitored mound per 5 minutes of each interval. Distinct nocturnal patterns were observed, with peak foraging activity between 0000 and 0600 hours, and reduced activity during the daytime. The multivariate regression analysis revealed that ant activity was significantly associated with the tested parameters ($p = 0.009$; $R^2 = 0.216$), where temperature ($p = 0.07$) and humidity ($p < 0.001$) were found to be significantly influencing the ant activity; however, the adopted model only moderately supports these variables due to the limited number of data points. This case study reports baseline information on affordable automated systems, which can be used in behavioural ecology. Further, the findings enhance the understanding of the environmental factors influencing ant foraging and suggest a methodological framework applicable to other small-bodied terrestrial invertebrates.

Keywords: behavioural ecology, computer vision, insect tracking system, low-cost monitoring technology, multi-sensor integration, optical flow algorithm

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INTRODUCTION

Social insects are species that live in cooperative groups of conspecific individuals, exhibiting behaviours such as resource sharing, collective defence, and cooperative communication (Price et al., 2011). These insects are highly sensitive to even subtle changes in environmental conditions, making them valuable subjects in ecological research. Many ecologists and biologists have explored the behaviours of social insects due to their potential as bioindicators, organisms that reflect the health or changing conditions of ecosystems. For instance, termites have been studied as indicators of soil fertility, honeybees for pesticide toxicity, and ants as markers of ecosystem integrity (Parikh et al., 2021).
However, due to their small size and tendency to form swarms, obtaining accurate and long-term behavioural data on these insects remains a challenge (Blinova & Dobrydina, 2019). Traditional sampling methods, such as pitfall traps, quadrat litter collection, and baiting (Underwood & Fisher, 2006), are often limited in precision and temporal resolution. Moreover, these methods of behavioural observation are often time-consuming, labour-intensive, and susceptible to observer bias. While modern technologies, including advanced vision systems and machine learning-based tracking tools (Abeysinghe et al., 2023; Mukherjee & Kulyukin, 2020), can offer high accuracy, their cost and complexity often hinder widespread adoption in field research. This highlights the need for an affordable, user-friendly system capable of continuous behavioural monitoring in natural environments.
In this study, it is presented a cost-effective, multi-sensor system developed using the ESP32 microcontroller, paired with a MATLAB-based computer vision algorithm utilising optical flow (Bjerge et al., 2021). Ants were selected as the model organism to test the system's efficacy. This approach not only provides high-resolution data on behavioural patterns but also demonstrates a scalable solution for ecological monitoring under field conditions. The objective of this study is to examine how ant activity correlates with environmental variation and to evaluate the performance and practicality of the multi-sensor system as a behavioural research tool.

Methodology

The preliminary study was conducted in an open natural habitat located at a home garden site in Homagama, Sri Lanka. The selected site featured a visible ant mound situated in a semi-shaded, vegetated area typical of suburban lowland Sri Lanka.

The experiment was carried out from 23rd to 29th August 2024, a period marked by intermittent rainfall and moderate humidity, characteristic of the inter-monsoon season. The observed Carpenter ants (Family Formicidae) colony was selected based on accessibility and consistent foraging activity, and identified using taxonomic keys at their family level (Dias, 2008).

The multi-sensor monitoring system

The multi-sensor monitoring system comprises two major subsystems: a Data Collection System, responsible for recording field data, and a Data Visualisation and Analysis System, which processes and summarises the collected information (Figure 1).

Data Collection System

An Android-based budget smartphone (Samsung Galaxy M02) equipped with a 12.98 MP CMOS sensor and f/1.9 aperture was used for continuous video recording. The camera was mounted on a tripod and positioned directly above the ant trail near the mound to capture clear footage of ingress and egress behaviour. A custom-developed Android application using Java and the CameraX API enabled automated video recording based on user-defined intervals and duration. Videos were recorded at a resolution of 852×480 pixels, 30 fps, and a bitrate of 4196 kbps. Audio was disabled to optimise storage.

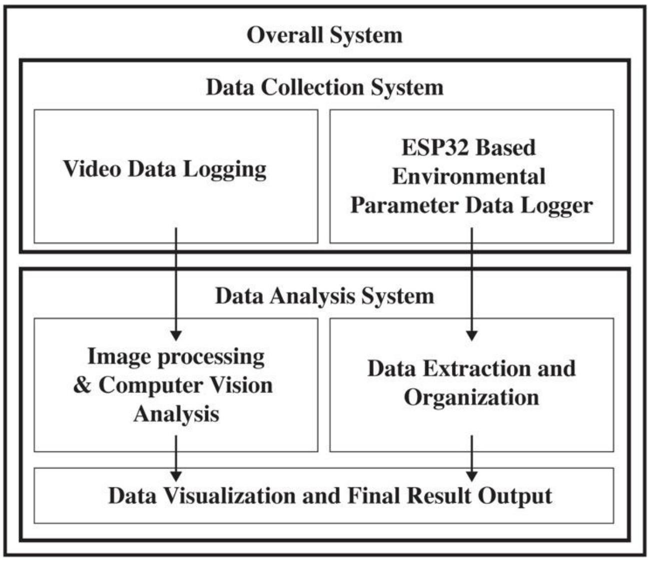


Figure 1: Basic Functioning of the System

Environmental parameters were logged using an ESP32-based microcontroller system featuring:

- Temperature & Humidity: DHT22 Digital Sensor (range: -40 °C to +80 °C; 0 to 100% RH)
- Light Intensity: Adafruit BH1750 Ambient Light Sensor (range: 1–65535 lx)

Sensors were mounted on the same tripod as the camera and placed approximately 30 cm from the ant mound to avoid interfering with natural behaviour while maintaining accurate environmental readings.

Sampling Interval and Data Logging

Environmental data were sampled at 15-minute intervals, and both real-time readings and timestamped logs were stored locally on a microSD card module. Simultaneously, data were transmitted via Bluetooth to a connected laptop when available. Power for the entire system was supplied by a 20,000 mAh power bank, replaced daily to ensure uninterrupted operation. The smartphone internally stored all video data, which was backed up to a computer at the end of each recording session. Recorded footage was processed using a custom MATLAB-based optical flow algorithm. This approach enabled object detection by identifying motion vectors associated with individual ants. A reference line was established within each frame to count ants entering and exiting the field of view, based on their direction of motion.

Data Analysis Strategy and Visualisation

To evaluate the relationship between environmental parameters and ant activity, Multiple Linear Regression was used to model ant ingress/egress counts as a function of temperature, humidity, and light intensity. Visualisation of activity trends and temporal variation were identified using interpolated time series plots in MATLAB.

RESULTS AND DISCUSSION

During the observation period of 23rd to 29th August 2024, a 5-minute video feed for each time interval of 15 minutes was captured. This, paired with the environmental parameter logging system, captured data over a total duration of 168 hours (7 Days), resulting in 672 discrete 15-minute intervals. Nearly 709 ants were observed moving either in or out of the monitored mound per 5 minutes of each interval. Distinct nocturnal patterns were evident, with a peak foraging activity occurring between 0000hrs and 0600hrs, while the reduced activity was observed during the daytime. These temporal activity shifts contrast with an observation of an existing literature where peak activity occurred at 1000hrs (Chong & Lee, 2009). A time series graph was plotted to visualise the ingress and egress behaviour over the full study period, clearly demonstrating these consistent daily cycles (Figure 2).

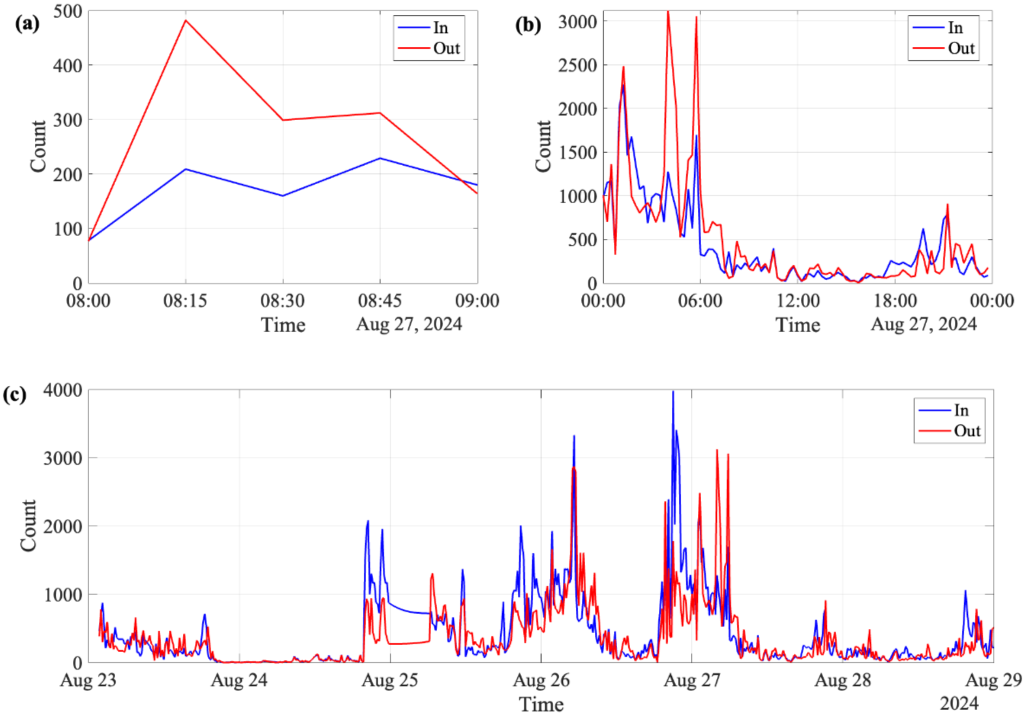
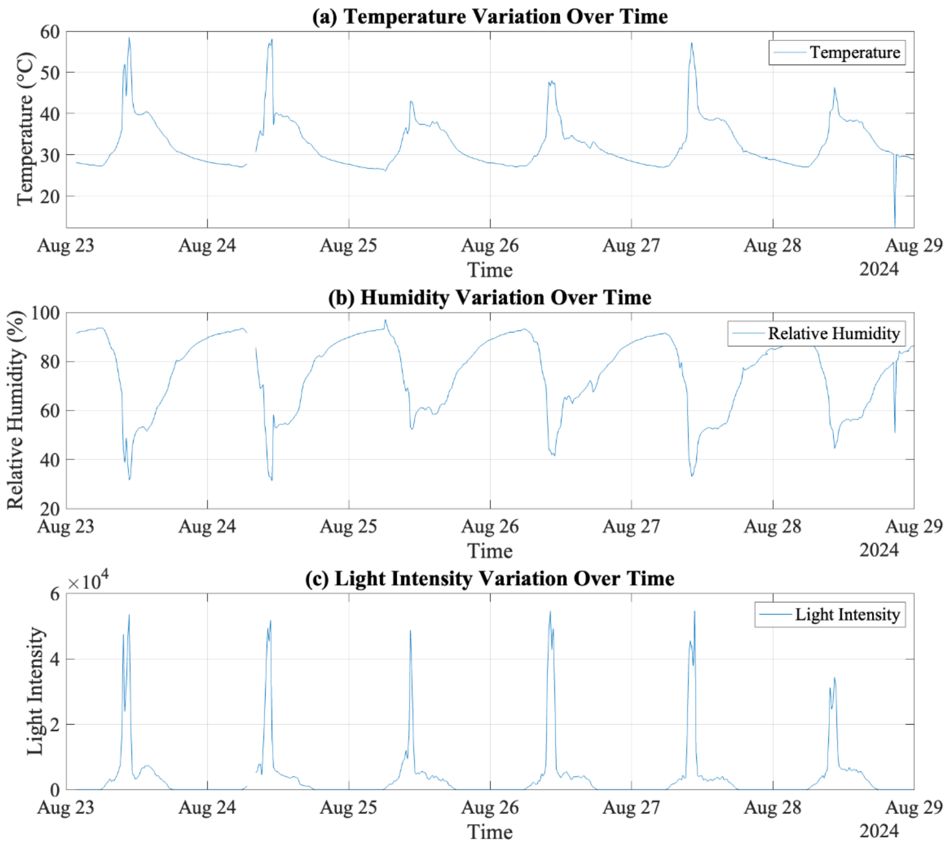


Figure 2: Visualisation of interpolated Ingress and Egress activity data collected by the system.

(a) Data from a one-hour window (08:00–09:00) on 27th August 2024, interpolated at 15-minute resolution. (b) Full-day trend for 27th August 2024. (c) Continuous data from 23rd to 29th August 2024. Missing values were linearly interpolated to demonstrate the system's capability to operate at variable temporal resolutions, with a minimum supported sampling interval of 15 minutes.

Environmental Parameter readings recorded during the same period showed measurable variability. The mean temperature of 30.2 °C, mean relative humidity of 75%, and mean light intensity of 3776 lx were observed (Figure 3). These patterns reflected the typical southwest monsoonal weather conditions in Sri Lanka (Climate Change Knowledge Portal, 2021). Time series graphs for each parameter revealed that temperature and light intensity closely followed a daily solar cycle, whereas humidity peaked during early mornings with a decline in the afternoon. The environmental data provides a crucial context as ant foraging behaviour has been shown to vary predictably with microclimatic fluctuations, particularly with temperature and humidity, which affects their desiccation risk and foraging efficiency (Destour et al., 2024).

The multivariate regression analysis revealed that ant activity was significantly associated with the tested parameters ($p = 0.009$; $R^2 = 0.216$), where temperature ($p = 0.07$) and humidity ($p < 0.001$) were found to be significantly influencing ant activity where with increasing temperature and humidity, the ant activity increases. When analysed separately, ingress activity was not significantly correlated with the environmental parameters ($p = 0.14$; $R^2 = 0.157$), and for egress activity, the regression model indicated a significant influence of environmental parameters ($p = 0.0007$; $R^2 = 0.218$) where humidity ($p < 0.001$) was found to be significantly influencing ant activity where with increasing humidity the ant egress activity increases. However, the adopted model only supported the variables moderately since the number of data points was low in the current study. According to previous literature ground ground-dwelling ants show a similar behaviour pattern, where with increasing temperature and humidity, a significantly higher activity is recorded, but no significant relationship was found with the light intensity (Chon



and Lee, 2009).

Figure 3: Weather parameter variations obtained from the datalogger: a.Temperature, b. Humidity, c. Light Intensity, variations over time.

CONCLUSIONS/RECOMMENDATIONS

The developed multi-sensor system offered a cost-effective, autonomous alternative to traditional sampling and high-end monitoring techniques. It enables continuous behavioural tracking of insect activity alongside environmental data logging with minimal human intervention. The system allows researchers to observe fine behavioural changes in response to short-term environmental fluctuations, offering value to ecological studies and real-time monitoring efforts. To enhance the system's effectiveness and applicability, future developments will focus on testing the setup across diverse terrain types, improving waterproofing for resilience in outdoor conditions, optimising the power supply through solar energy integration, and calibrating all sensors to standardised measurement units to ensure accuracy and reliability.

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