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Multi-sensor data utilization of unmanned aerial vehicle for wildlife monitoring in Komodo National Park

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ABSTRACT

The use of unmanned aerial vehicles (UAVs) equipped with multispectral and thermal sensors provides a promising approach to wildlife monitoring, especially in the dynamic environment of Komodo National Park. This study explores the effectiveness of UAVs in tracking Komodo dragons and other wildlife using thermal imaging, which distinguishes animals based on body temperature contrasts with the surrounding environment. Thermal sensors detect wildlife more effectively in the afternoon, as animals like the Komodo dragon exhibit higher body temperatures compared to the cooler surroundings. Challenges, however, arise in the morning when animals body temperatures are closer to the environment, making them harder to detect. Factors such as fog, animal movement, and sensor limitations also impact detection accuracy. The study highlights the advantages of combining UAV thermal imaging with multispectral data to enhance monitoring accuracy. Despite the challenges, this method proves to be an efficient tool for wildlife management and conservation in remote, vast areas like Komodo National Park.

Keywords: unmanned aerial vehicle, multisensor, thermal, wildlife, Komodo dragon.

INTRODUCTION

The assessment of the thermal environment is one of the oldest judgments made by humans, dating back to the 17th century (Mahersons, 1962). Psychophysical relationships between thermal parameters and human comfort have been established, with air velocity having a beneficial effect in warm conditions but causing draught sensations in cooler temperatures (Olesen et al., 2001). Rising environmental temperatures are predicted to severely impact biodiversity (Price et al., 2018), and temperature is a major factor in disease dynamics in amphibians and reptiles, influencing survival and recovery (Warwick, 2003; Noble et al., 2017).

The Komodo dragon (*Varanus komodoensis*), the largest monitor lizard, is confined to five fragmented populations in the Lesser Sundas, Indonesia, with four populations in Komodo National Park (Jessop et al., 2004). Loh Buaya on Rinca Island supports a large population within 500 km², with habitats ranging from deciduous monsoon forest to savannah and mangrove ecosystems. Komodo dragons are categorized into three size groups: small (5–20 kg), medium (20–40 kg), and large (> 40 kg) (Harlow et al. 2010). Smaller dragons are more active in direct sunlight, while larger dragons exhibit different ecological behaviors, including diet and thermoregulation (Jessop et al., 2006; Harlow et al., 2010).

Technological advancements, such as camera trap, are widely used for population monitoring. Camera trap surveys can yield visual data, enabling the identification of species as well as their population density (Khalil et al., 2019). Remote sensing technology continuously evolving, producing various types of images captured by multiple sensors (Andiko et al., 2019). The effectiveness of passive infrared camera traps relies on thermal contrasts between animals and their environment (McCarthy et al., 2022). Both baited and non-baited camera methods remain in use for Komodo dragon monitoring (Purwandana et al. 2022), though survey costs remain high (Gonjales et al., 2016) and monitoring sensitive areas using ground surveys risks causing damage to the values for which they are being protected (Bollard et al 2022). UAV technology have accelerated, allowing them to be used as large-scale and detailed mapping tools (Novianto, 2024). The features advanced sensors, including thermal, high-resolution cameras, and gas sensors, allowing for accurate, continuous monitoring of forests. Its autonomous and programmable capabilities make it ideal for regular patrols of critical areas (Paredes et al., 2023). UAV offer great potential for monitor plant, wildlife monitoring, but their real-world use is still limited, but the fast developing technologies of UAV, sensor, machine learning pave the way for automated monitoring, IOT, and wildlife monitoring (Rolland et al., 2024; Wijayanto et al., 2024; Povlsen et al., 2023; Mitra et al., 2021; Kumarasan et al., 2020; Fox et al., 2020; Gonzalez et al., 2017).

VTOL (Vertical Take-Off and Landing) aircraft combines the vertical take-off capabilities of multi-rotors with the long-range efficiency of fixed-wing aircraft. It eliminates the need for runways, allowing for safe landings in various field conditions, while offering longer flight times and higher cruising speeds than multi-rotors, making it more efficient for tasks like field mapping (Lluis, 2023). UAV technology, particularly VTOL types, is increasingly used for large-area monitoring, with the ability to detect animals based on body heat, even at night (Burke et al., 2019). The use of the MicaSence Altum PT multi-sensor on VTOL aircraft for wildlife monitoring has yet to be explored. This article discusses the challenges of determining the optimal timing for the thermal sensor to effectively identify wildlife, as well as the necessary flight altitude for monitoring. The multi-sensor imaging approach is a relatively new technique in Indonesia for mapping wildlife. By combining multispectral sensors, such as thermal and RGB, the most precise radiometric data can be achieved. A key feature of this technology is the integrated thermal model, which is expected to identify the distribution of wildlife, particularly Komodo dragons, based on the heat emitted by their activities. For instance, juvenile Komodo dragons are often seen basking in the sun, medium-sized ones tend to move more slowly between sunlight and shaded areas, while larger Komodos remain relatively stationary throughout the afternoon (Harlow, 2010).

MATERIAL AND METHODS

Collection of data

The location of the study

This study was conducted on Loh Buaya, Rinca island, Komodo National Park from March through to July 2023 (Fig. 1). Data collection for this research was conducted in the morning (06:00–07:00) and in the evening (16:00–18:00). These time periods were chosen to observe differences between the Komodo dragons and their environment under varying temperature conditions.

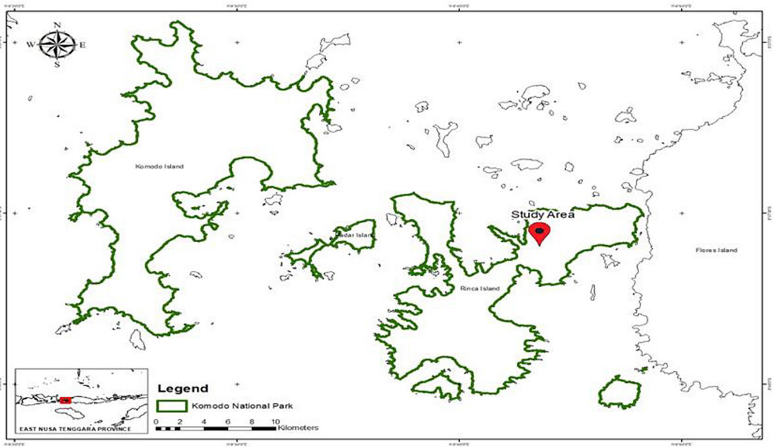

Figure 1. The Map of the research location at Loh Buaya within the Komodo National Park, East Nusa Tenggara Province

Komodo dragons experience their lowest body temperature between 06:00–07:00, with the highest temperatures occurring in the afternoon (Harlow et al. 2010).

The UAV monitoring covered an area of 150 hectares, divided into two separate flight plans. The drone operated at an altitude of approximately 80–100 meters above ground level (AGL).

Tools and research materials

In this study, the focus was on observing wildlife within Komodo National Park using software tools such as Qbase 3D, Agisoft Metashape, and ArcMap 10.8. The primary equipment included a Trinity F90+ VTOL UAV, equipped with a MicaSense Altum PT series camera for capturing images and data through its advanced sensors. The Trinity F90+ is a hybrid VTOL UAV that combines fixed-wing and multirotor capabilities (Wijayanto et al 2024), enabling it to achieve flight durations of up to 90 minutes while carrying a multi-sensor camera. Additionally, the Trinity F90+ allows for easy replacement of sensors, referred to as payloads, based on specific operational requirements (Fig. 2)

The multisensor used in this study was the MicaSense Altum PT, specifically designed for UAV or drone applications. Some modifications were made to its structure to ensure compatibility with the payload specifications of the Trinity F90+. This sensor is capable of capturing data across six spectral bands: blue, green, red, red edge, near-infrared (NIR), and FLIR thermal. Data from these sensors is used to produce multispectral and thermal images of the monitoring area. These images can be analyzed for various applications, including environmental mapping. Additionally, the MicaSense Altum PT series is equipped with a thermal sensor, enabling effective monitoring of target objects. (Fig 3).

The multisensor camera used in this study was the MicaSense Altum PT, specifically designed for UAV or drone applications. Each sensor within the MicaSense Altum PT camera has distinct specifications. The multispectral sensor offers a resolution of 2064 × 1544, while the thermal sensor provides a resolution of 320 × 256. The image ratio of the multispectral sensor is smaller compared to the thermal sensor. In terms of optical distance calculation, referred to as focal length, the thermal sensor has a shorter focal length than the multispectral sensor. This results in a wider field of view for the thermal sensor, allowing it to capture more objects within a single frame. At a flight altitude of 120 m, the ground sampling distance (GSD) is approximately 5.28 cm per pixel for the multispectral sensor and 33.5 cm per pixel for the thermal sensor. In this study, the panchromatic band feature was disabled due to memory limitations during data storage while capturing image data. A detailed comparison between the multispectral and thermal sensors of the MicaSense Altum PT is presented in (Table 1).

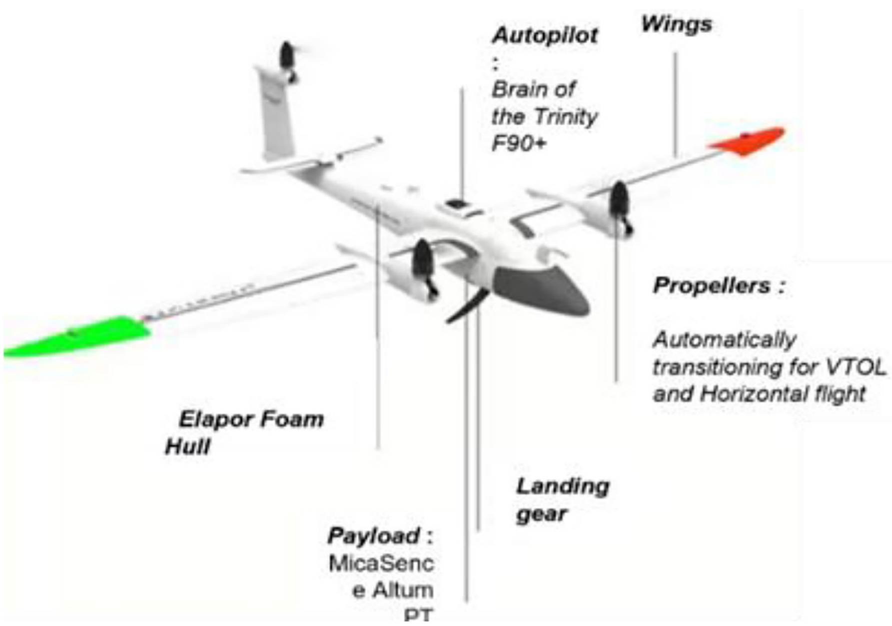

Figure 2. UAV Trinity F90+

Figure 3. The Altum PT Payload for the Trinity F90 series

Table 1. MicaSence Altum PT Sensor Specification

Specification	Multispectral band	Thermal band
Sensor resolution	2064 × 1544 (3.2 MP)	320 × 256 (0.08 MP)
Image ratio	4: 3	5: 4
Focal length	8 mm	4.5 mm
Field of view	48° HFOV × 36.8° VFOV	48° HFOV × 39° VFOV
GSD at 120 m height	5.28 cm/pixel	33.5 cm/pixel

Type of data

The multispectral dataset for wildlife detection consists of a combination of visual imagery using Red Green Blue (RGB) and specifically a thermal band. Each 1 snapshot photograph contains 6 bands with a pixel resolution of 2064 × 1544 for the multispectral bands, while the thermal band has a pixel resolution of 320 × 256 per capture. The following shows the result of a single photo capture process in (Fig. 4). Multispectral bands (RGB) bands and other spectral bands (Red Edge and Near-Infrared) are used to capture visible light and reveal details about the environment and vegetation. These bands help differentiate various objects in the landscape, including wildlife, by identifying characteristics such as water, and soil composition. Thermal band captures temperature variations in the environment, which helps to identify living organisms (like Komodo dragons) based on their heat temperate. This is especially useful for detecting wildlife, as animals often stand out from the surrounding environment due to their temperature differences. A total of 47,945 photos were captured, which will be processed into orthophoto images according to the respective observation times (Table 2).

Table 2. Total number of photos captured for each AOI and time period

ID Folder	Total photo			
	AOI 1		AOI 2	
	Morning	Afternoon	Morning	Afternoon
000	1.205	1.200	1.200	1.200
001	1.200	1.200	1.200	1.200
002	1.200	1.200	1.200	1.200
003	1.200	1.200	1.200	1.200
004	1.200	1.200	1.200	1.200
005	1.200	1.200	1.200	1.200
006	1.200	1.200	1.200	1.200
007	1.200	1.200	1.200	1.200
008	1.200	1.200	1.200	1.200
009	1.200	1.200	1.008	630
010	330	372	N/A	N/A
Total	12.335	12.372	11.808	11.430

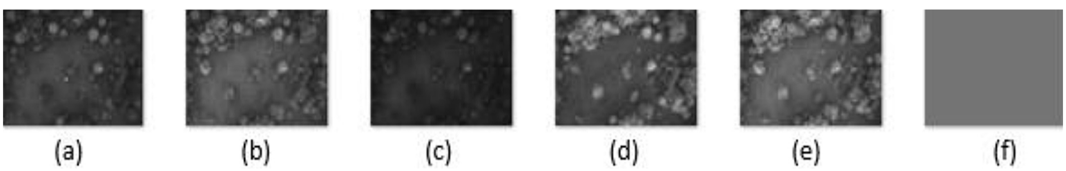

Figure 4. (a) Red, (b) green, (c) blue, (d) red edge, (e) near infrared (NIR) and (f) FLIR thermal

Methodology

This research was conducted in several stages, including data acquisition, data processing, and image object identification. The initial step involved preparing the Trinity F90+ UAV, equipped with the MicaSense Altum PT camera. Flight planning was carried out using Qbase 3D software, which included configuring parameters such as elevation, side overlap, forward overlap, and flight path direction. These settings were adjusted to ensure the trigger value approached 1 or displayed a green Ground Sampling Distance (GSD) indicator, signifying a safe flight area with no obstacles. Once configured, the UAV was ready for image capture. The Trinity F90+ is capable of Vertical Takeoff and Landing (VTOL) and can seamlessly transition between helicopter mode and fixed-wing aircraft mode during flight. The overall workflow of the research methodology is illustrated in (Fig. 5).

Determincation of the elevation

Figure 6 illustrates the UAV flight mission workflow, highlighting the selection process

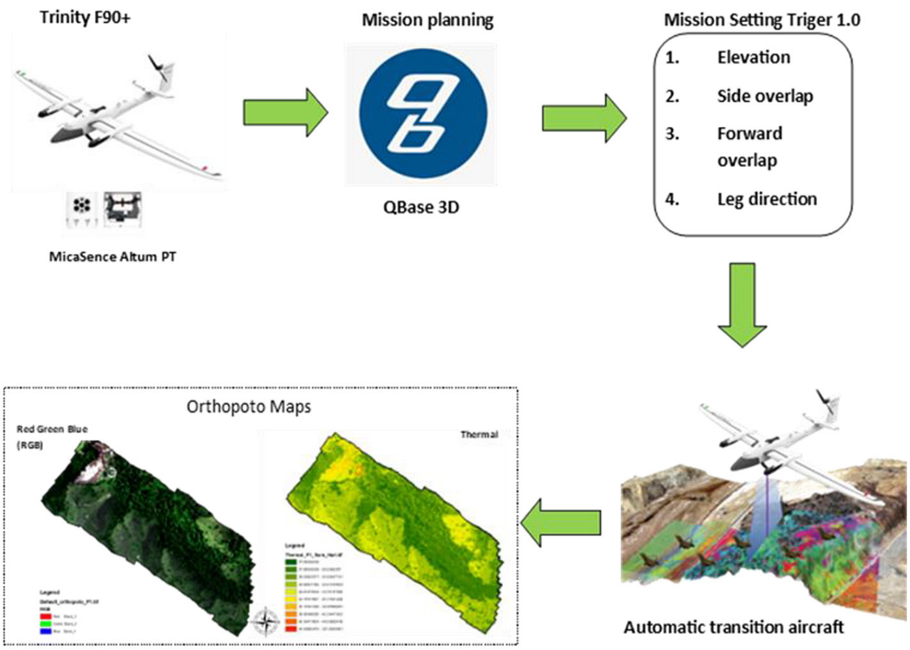

Figure 5. Flight mission process to obtain a set of images at the research location, which will then undergo image calibration and object analysis from the combination of RGB and thermal images result

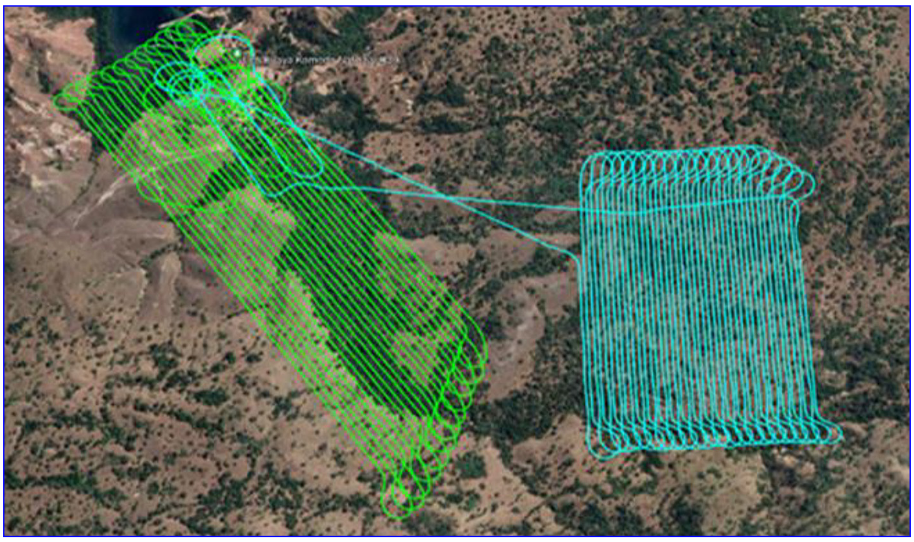

Figure 6. The focus of the research is AOI 1 (green) and AOI 2 (blue)

for determining sampling plots, Area of Interest (AOI) surveys, and the analysis required to achieve optimal settings. This step was crucial for obtaining accurate and safe altitude information. To ensure flight safety and efficiency, flight simulations were conducted using 30 m resolution SRTM data .

Our mission setting determination was tested using QBase 3D software at several altitude levels to obtain simulated flight values. Both AOI 1 and AOI 2 were flown at an altitude of 100 meters above sea level (mdpl). In AOI 1, we tested different side overlaps and forward overlap settings compared to AOI 2, resulting in different index combinations for AOI 1 and AOI 2. The summary element table also shows simulations of flight path length and battery indicators including battery time and power present (Table 3).

Based on terrain data from the first location (AOI 1), the average hill elevation ranges between 0–70 meters above sea level (masl). Therefore, the optimal flight altitude for the Trinity F90+ UAV at this site is above 80 masl to ensure safe operation and avoid potential collisions. In contrast, flight simulations conducted at the second location (AOI 2) revealed an average hill elevation ranging from 40–140 masl. Consequently, the recommended flight altitude for this area is above 150 masl to maintain a safe clearance during operations (Fig. 7). The flight altitude variation analysis reveals that altitudes between 60 m and 80 m still pose a risk for drone operation, with a significant potential for collisions with mountains or hills. During the flight simulation, it was observed that a 10 m difference along the flight axis resulted in a trigger value below 1.0. Based on this analysis, the optimal average altitude above ground level (AGL) for both locations is determined to be 100 m. This altitude ensures a safe distance between the UAV and the terrain along the Y-axis.

Table 3. Determination of mission settings and element summary planned at AOI locations

Mission setting	AOI 1	AOI 2
Altitude (m)	100	100
Side overlap (%)	60	65
Forward overlap (%)	60	65
Trigger index	0.6	0.9
Average GSD (cm/px)	1.06	1.5
Element summary		
Flight length (km)	54.6	45.6
Flight time	1 h 3 m 22 s	53 m 56 s
Battery usage (%)/ 1 Bat	51	43
Triger count	2543	1840

Determination of time of study

In addition to considering elevation factors, it is essential to determine the optimal time for conducting research, particularly for monitoring Komodo dragons. The temperature difference between the animal and its surrounding environment significantly influences the accuracy of thermal sensor imaging. To prevent temperature overlap between the target object and the background, the study was conducted in two sessions: morning (06:00–07:00) and afternoon (17:00–18:00). These time periods were selected because Komodo dragons typically reach their lowest and highest body temperatures during these hours (Harlow et al., 2010). When the ambient temperature and the animal's body temperature have not yet reached their peak, thermal cameras can effectively detect animal objects with a temperature difference of at least 3 °C above the environment, minimizing data overlap. Furthermore, wind conditions at the survey location are a critical factor for UAV operations. Wind speeds exceeding 11 m/s can disrupt the UAV's flight stability, potentially triggering system errors and causing the aircraft to automatically return to its home base. (Quantum, 2020).

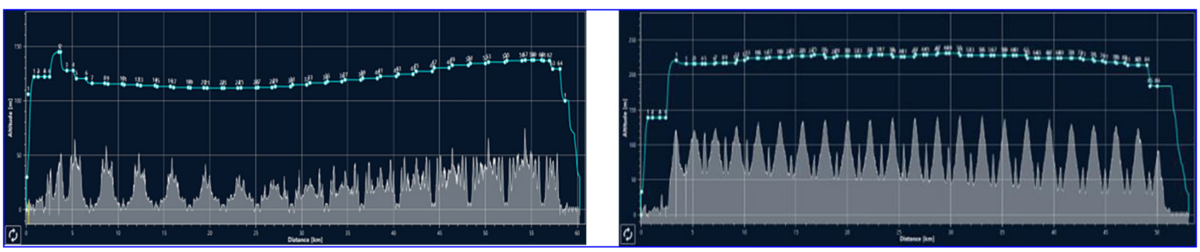

Figure 7. Terrain elevation at AOI 1 (left) and AOI 2 (right)

Data analysis

UAV data processing

Resulting images from UAV mission plan were geographically coded using the UAV fly-log notes based on base-station which are downloaded in each flight activity. Furthermore, this image was processed using Agisoft Methashape 1.6.0 software. This software is widely used due to its motion structure algorithms and 3D modelling implementation which rely on 2D images overlapping.

Through a well-defined setting and steps including photo orientation, densely cloud point drop, deep filtering and sensor location optimization, high-quality 3D models were produced, and this resulting model was exported as ortho-mosaic. Data processing can be seen in (Fig. 8).

Red, green, blue (RGB) detection

The process of wildlife detection based on RGB combination aims to identify and separate wildlife objects from the background in RGB images. Here are the steps involved in this image pre-processing:

1. Conversion to RGB combination
2. Normalization: normalize the image to enhance contrast and image quality
3. Noise removal: use techniques such as filtering to remove noise from the image

Thermal detection

The process of wildlife detection based on thermal images involves the use of specific image processing techniques to distinguish animal objects from the background based on the heat emitted by these objects. The thermal data generated from the Altum PT has a unit of Kelvin, and the next step is to convert it into Celsius, with the following process (1):

$$°C = °K - 273.15 \quad (1)$$

where: °C is Celsius degree and °K is Kelvin degree.

RESULT AND DISCUSSION

Data analysis

Pre-survey area assessment

Prior to the monitoring, an assessment was conducted to identify the potential wildlife species that could be found at the research location. Wildlife identification was carried out through direct observations, and several of the animals encountered are depicted in the following Fig 9:

The wildlife observed varied in size and shape. The Komodo dragon is longer than the Timor deer but shorter than the wild buffalo, which has a more rounded body. The body length of each species observed can be identified based on encounters within their respective AOI

The present of wildlife AOI 1

Object detection at the research site was conducted to identify active objects that could be captured by the multispectral sensor. The lack of knowledge regarding the distribution of wildlife serves as the basis for testing the use of multi-sensor and thermal sensors to distinguish objects from the background area.

Figure 10 show first test conducted in the morning, an orthophoto map was obtained with a study area of approximately 86 hectares. The initial observation showed that the morning

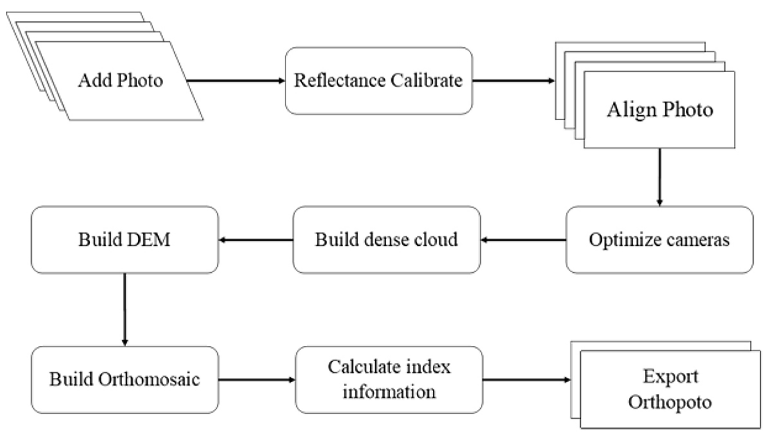

Figure 8. Orthopoto data processing for MicaSence Altum PT

Figure 9. Wildlife observed at the research location: Komodo dragon, Timor deer, and wild buffalo

temperature ranged from 17–29 °Celsius. The image displayed on the orthophoto indicated the presence of fog or haze. Based on the observation, two wildlife objects were clearly identified in the RGB image. The following is the distribution of wildlife found at the first location in the morning.

Specifically, the wildlife found at the first location in the morning consisted of one Komodo dragon with body length of 2.01 meter and one deer length 1.2 meter. When compared to the body temperature of the animals, the body temperature of the deer was not detected by the sensor, unlike the Komodo dragon, whose body temperature was identifiable by the thermal sensor, with a temperature of around 25 °C. The following is a comparison table between the RGB image and the thermal image showing the observation results (Fig. 11):

Observations were conducted at different times on the same location, in the afternoon, to observe the differences in the appearance of the orthophoto image and the environmental temperature conditions that could be mapped by the drone. The RGB image display showed a clearer identification of wildlife objects. Based on the mapping in the afternoon, the identified location was different from the one found in the morning, indicating that the wildlife had moved from the morning to the afternoon:

In Figure 12, show seven wildlife were found, consisting of 1 Komodo dragon, 3 deer, and 3 buffalo. The Komodo dragon was found in an open and dry area, with an estimated body length of about 1.8 meters. Its body temperature was the same as the surrounding environment, ranging from 33–34 °C, which is lower than the optimal body temperature for a Komodo dragon, which is around 35.5 °C.

Meanwhile, three deer were found, with an average body length of about 1 meter. Two of the deer had body temperatures like the environment, between 30–32 °C, while one deer had a higher body temperature, ranging from 33–34 °C. Additionally, three wild buffalo were found in a wallowing area, with an average body length of around 1.5 meters. Two buffalo showed the highest body

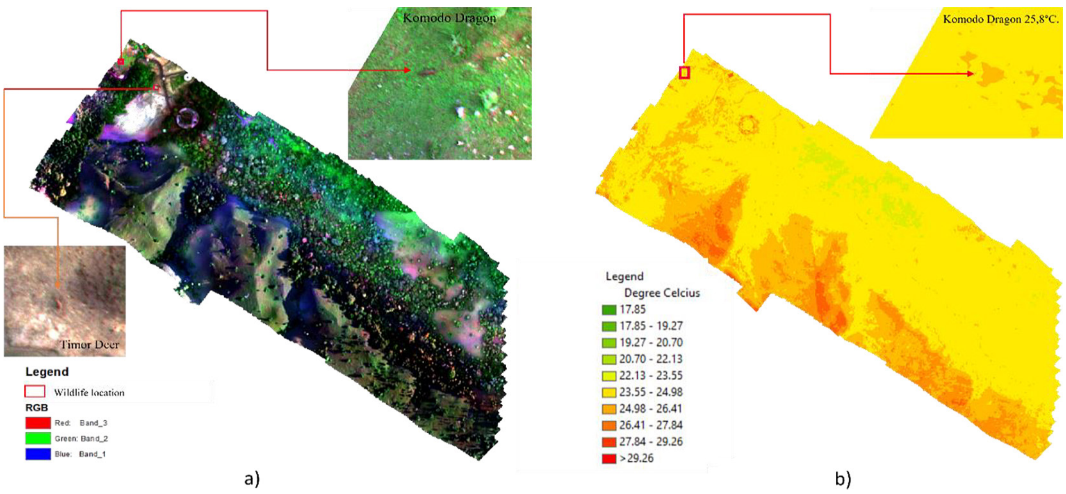

Figure 10. The orthopoto result of the AOI 1 in the morning (a) RGB imagery (b) thermal imagery

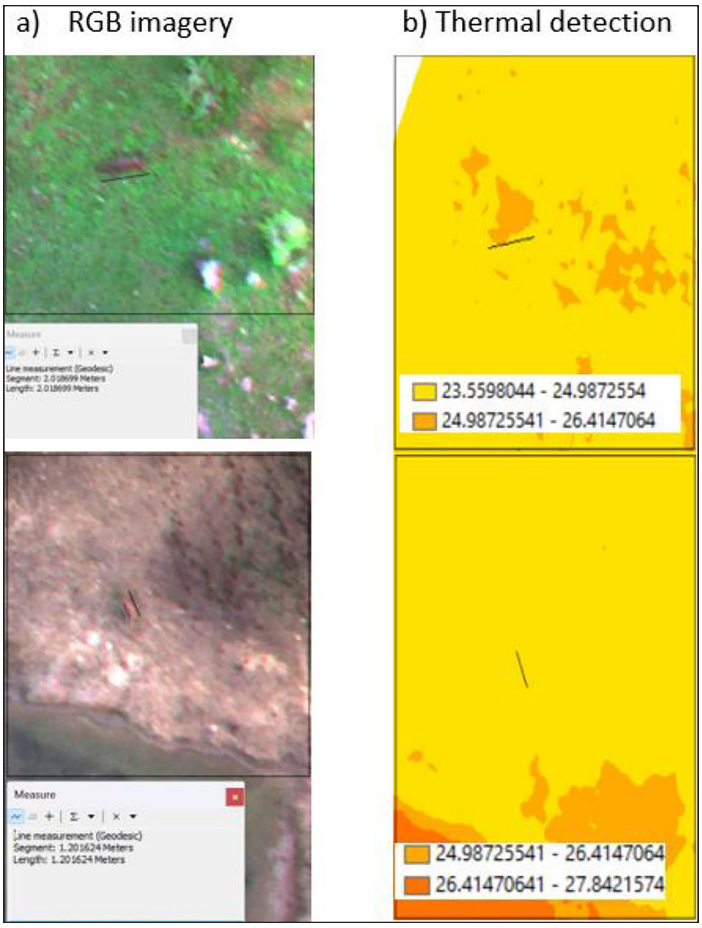

Figure 11. Zoom in AOI 1 morning imagery (a) RGB imagery (b) thermal imagery

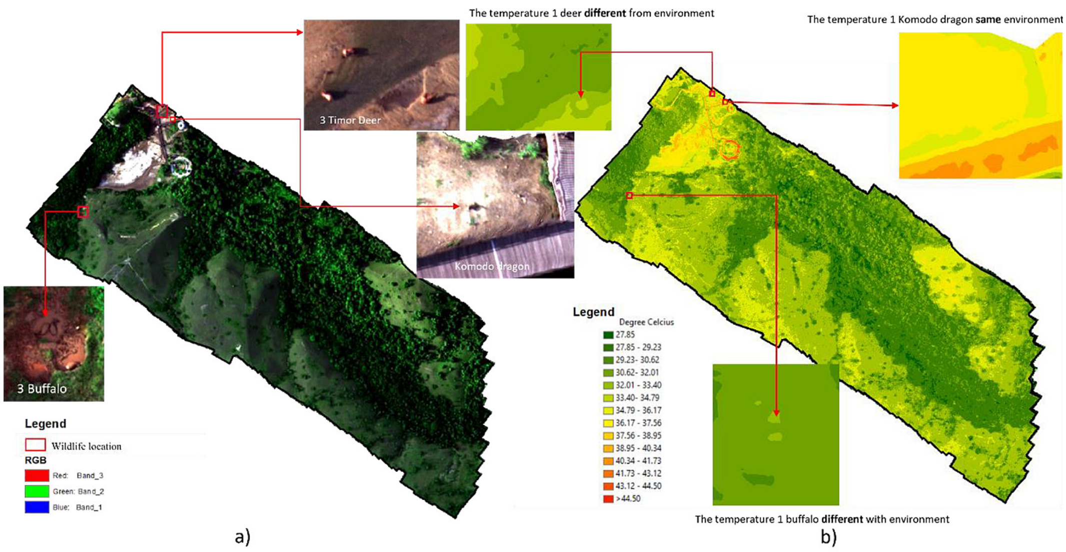

Figure 12. The orthopoto result of the AOI 1 in the afternoon (a) RGB imagery (b) thermal imagey

temperature, around 32 °C, while one buffalo had a body temperature like the environmental temperature, ranging from 30–31 °C. The following is the RGB and thermal display related to the four wildlife individuals found (Fig. 13):

The presence of wildlife AOI 2

Wildlife observations were conducted at a different location with an area of approximately 58 hectares. The morning observation started at

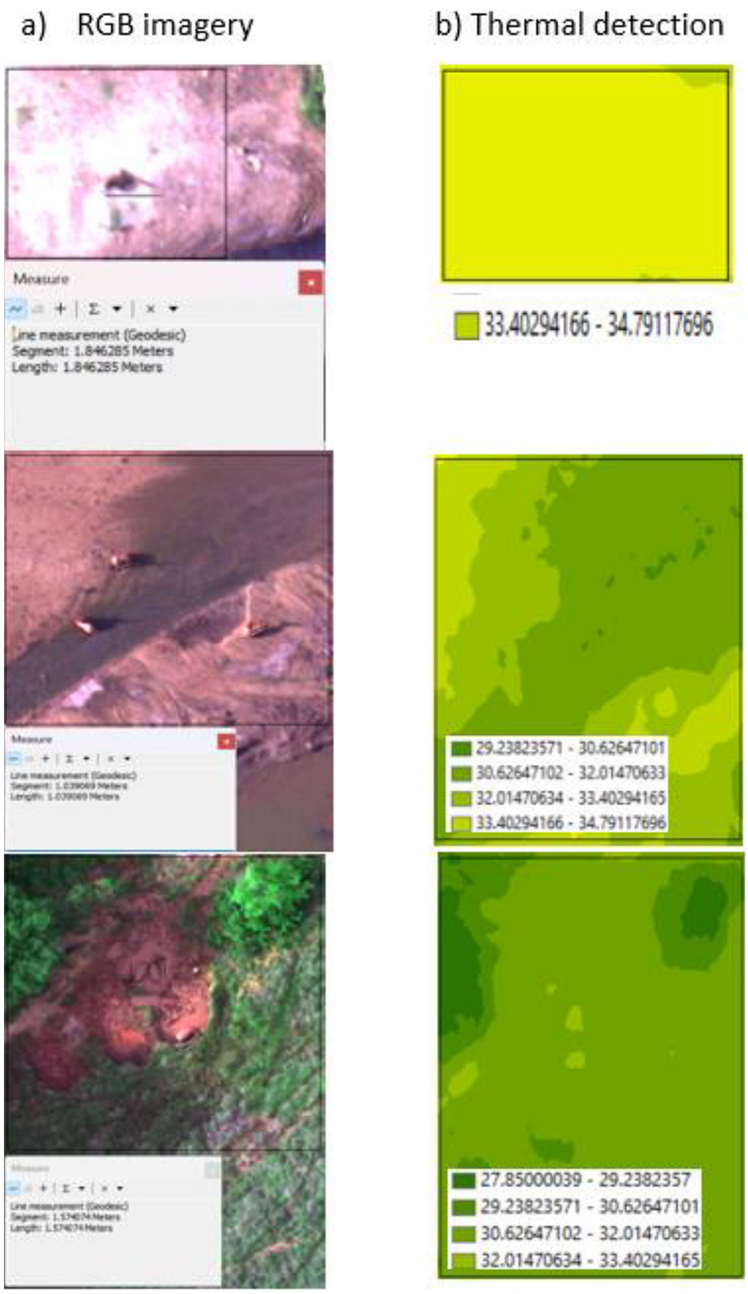

Figure 13. Zoom in AOI 1 afternoon imagery (a) RGB imagery, (b) thermal imagery

06:30, where 3 buffalo with average length 1.43 meter were found at this location. The observed activity in the morning was the buffalo wallowing.

In Figure 14 The morning session commenced at 06:30, implying an early start to capture the animals activities during this time. Three buffalo were identified at the site, with an average body length of 1.43 meters, providing information about their size and context about the species under study. During the morning, the buffalo were seen wallowing, which means they were rolling or resting in mud. This behavior is typical of buffalo and other animals as a way to cool down, shield their skin, or prevent irritation from insects (Bhakat, 2020). The temperature at the location ranged from 25 °C to 41 °C. The thermal temperature at the observation site fluctuated between 25 °C and 41 °C, indicating temperature variations that could influence the animals' behavior, such as their activity patterns or how they cope with heat, for instance, by wallowing in mud to stay cool. The body size of the buffalo and thermal details can be seen in detail zoom in (Fig. 15). In the afternoon, observations were conducted at 16:30, and 1 buffalo individu were found with length 1.5 meter. The RGB image showed the buffalo

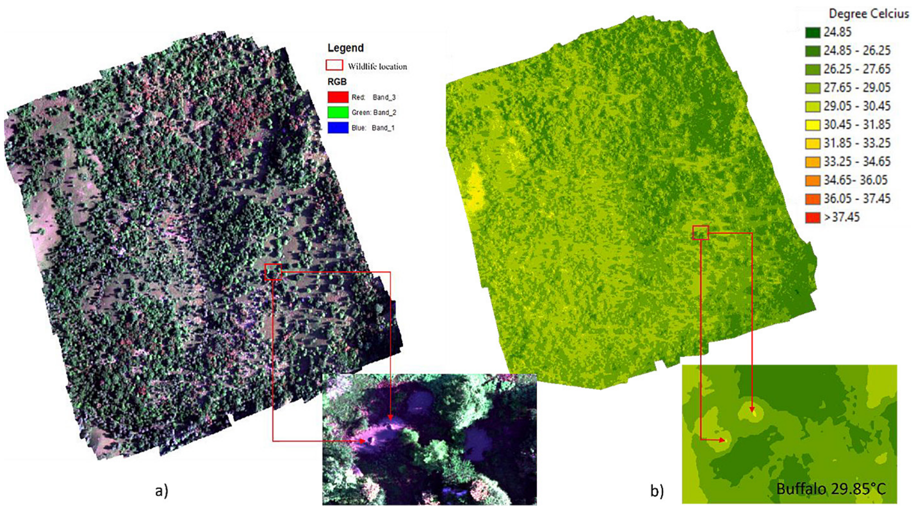

Figure 14. Orthopoto result of the AOI 2 in the morning (a) RGB imagery (b) thermal imagery

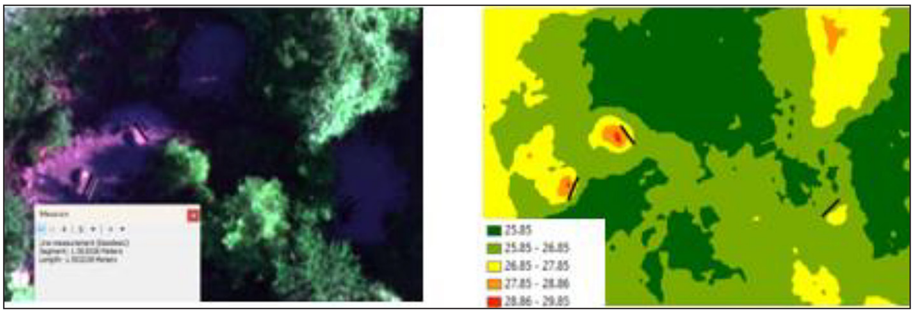

Figure 15. Zoom in AOI 2 morning imagery (a) RGB imagery (b) thermal imagery

activity within the wallowing area. The following is the orthophoto display of the RGB image at the second location (Fig. 16). In the thermal image, the detected temperature ranged from 24 °C to 37 °C around the location. The following shows the specific differences in the wildlife found, including one Komodo dragon and one deer. When comparing the temperatures between the objects, the body temperature of the deer was not detected by the sensor, which contrasts with the Komodo dragon's body temperature, which was identifiable by the thermal sensor, with a temperature ranging around 25 °C. The body size of the buffalo RGB and thermal imagery details can be seen in detail zoom in (Fig. 17).

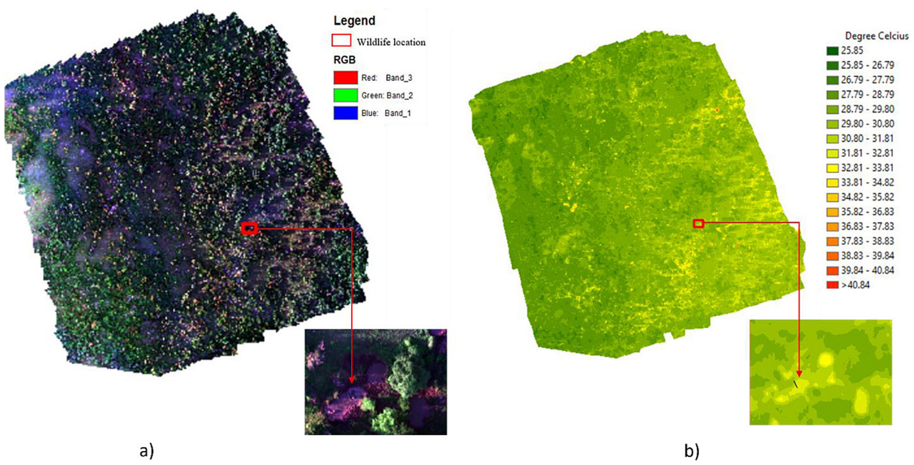

Figure 16. The orthopoto result of the AOI 2 in the afternoon (a) RGB imagery (b) thermal imagery

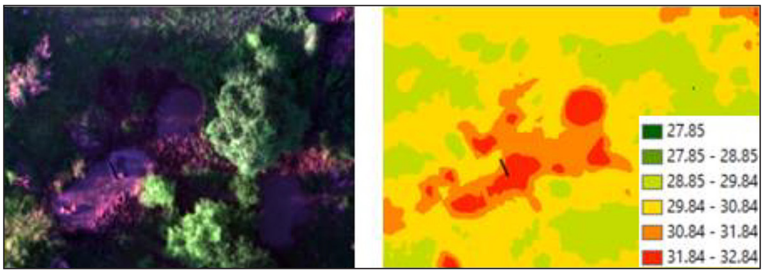

Figure 17. Zoom in AOI 2 morning imagery (a) RGB imagery, (b) thermal imagery

Discussion

Comparison of wildlife body temperature detection in the morning and afternoon using thermal sensors

Based on the observations you provided, the difference in the body temperature of wildlife detected by the UAV is more distinct in the afternoon compared to the morning. Here are the underlying reasons. In the morning observation, the body temperature of some wildlife, such as deer, was not clearly detected by the thermal sensor. This suggests that the body temperature of the animals in the morning may be more like the surrounding environment, making it more difficult to distinguish the animals from the background using the thermal sensor. For the Komodo dragon, its body temperature was identified as around 25 °C, which is still quite close to the environmental temperature, making the difference less noticeable. and the afternoon observation, the body temperature of the wildlife was easier to differentiate. For instance, the Komodo dragon was found with a body temperature of around 33–34 °C, which is higher than the surrounding environmental temperature of around 30–32 °C. The more significant temperature difference between the Komodo and its surroundings made it easier to identify the animal in the thermal image. Similarly, the deer and buffalo showed more distinct body temperature differences from the environment in the afternoon, making detection by the thermal sensor easier. The deer and buffalo, with body temperatures differing from the environmental temperature, were easier to distinguish in the thermal image in the afternoon.

The distinct differences in body temperatures, especially between the morning and afternoon observations, emphasize how these animals adjust to varying environmental temperatures. The afternoon observations were more effective at differentiating body temperatures, thus enabling clearer identification of these species via thermal sensors. This highlights the importance of understanding animal thermoregulatory behaviors and their adaptive responses to temperature shifts, which are crucial for conservation strategies, especially in the context of climate change where environmental temperatures are increasingly variable (Bonebrake et al., 2020). For instance, species like the Komodo dragon engage in thermoregulation through basking in sunlight during cooler parts of the day, and this behavior is essential for maintaining optimal body temperature (Harlow et al., 2010). Understanding these patterns through thermal monitoring can help in tracking the health, movements, and habitat usage of these species, contributing to better-informed conservation actions (Ivosevic et al., 2015).

Challenges in using UAV with thermal sensors

Based on the analysis and discussion above, several challenges encountered during surveys using drones with thermal sensors include:

1. Insignificant temperature differences – in the morning, the body temperature of some animals, such as deer, was not clearly detected by the thermal sensor. This is because the body temperature of the animals in the morning may be like the surrounding environmental temperature, making it difficult for the thermal sensor to differentiate between the animal and the background. When the body temperature of the animals is close to the ambient temperature, the thermal sensor struggles to accurately identify the object, reducing the effectiveness of the sensor in such conditions.
2. Changing environmental conditions – the presence of fog or haze visible in the orthophoto image in the morning can affect the quality of the thermal image. Fog particles or humidity in the air can absorb or block the thermal radiation emitted by animals, thus reducing the accuracy

of temperature detection by the thermal sensor. Rapid changes in environmental temperature (such as temperature variations from morning to afternoon) can also complicate consistent detection because the thermal sensor must adjust its temperature measurements to account for these changes.

3. Detection range and sensor resolution limitations – the detection range of the thermal sensor on the drone is limited by several factors, like flight altitude and the quality of the sensor itself. At greater distances, the thermal sensor may struggle to detect objects clearly, especially if the objects are not large enough or do not have a significant temperature difference compared to the background. The limited resolution of the thermal sensor can also affect its ability to detect smaller objects or those with temperatures that are very close to the surrounding environment.
4. Limitations in differentiating similar objects – some animals or objects in the environment, which have body temperatures like the surrounding temperature (such as buffalo and deer in the morning), are difficult to distinguish clearly using the thermal sensor. This adds difficulty in differentiating between animal objects and the background in thermal images.
5. Influence of animal movement – the movement of animals from morning to afternoon also presents a challenge, as the position and body temperature of the animals can change over time. Animals that move from cooler areas to warmer areas (for example, a Komodo dragon moving to a more open and hotter area in the afternoon) will show more noticeable temperature changes in the thermal image. However, if the animals move to cooler areas, detection may become more difficult.
6. Limitations of using a single sensor type – thermal sensors work by detecting temperature differences, but for more accurate object identification, combining with other sensors (such as multispectral or RGB) is often necessary. Relying solely on the thermal sensor may reduce accuracy in some conditions, particularly when the temperature difference between objects and the background is not significant.

This study is highly valuable in advancing our understanding of wildlife monitoring and conservation, the use of UAVs equipped with thermal sensors for wildlife monitoring comes with certain challenges. One significant difficulty observed in this study was the inability to clearly detect species like deer in the morning, as their body temperatures were too like the surrounding environment. This issue is well-documented, with prior studies noting that thermal sensors struggle to detect animals whose temperatures are close to the ambient temperature (Boyle et al., 2013). Additionally, environmental conditions, such as fog, haze, or humidity, can degrade thermal imagery. These factors absorb or block thermal radiation, making it harder for the sensors to distinguish animals from the background (McManus et al., 2016). The limitations of the UAV's thermal sensor resolution and range were also evident. At greater distances or higher altitudes, smaller animals or those with less distinctive body temperatures become harder to identify (Rietz et al., 2023). To overcome these limitations, combining thermal sensors with other technologies like multispectral or RGB sensors has been shown to improve object detection and provide more reliable results (Verfuss et al., 2019).

Despite these challenges, UAVs with thermal sensors have great potential in wildlife monitoring and conservation. Their ability to monitor animals remotely reduces human disturbance, which is especially important in sensitive or protected areas (Povlsen et al., 2023). As UAV and multisensor technologies continue to evolve, they offer even greater opportunities for large-scale, cost-effective monitoring, particularly in remote or difficult-to-access regions (Loots et al., 2022). By improving sensor accuracy and integrating multiple sensor types, UAV could become a critical tool for tracking endangered species like the Komodo dragon, allowing for more detailed insights into their distribution and behavior (Corcoran et al., 2021).

UAV-based thermal monitoring presents a powerful tool for understanding wildlife thermoregulation and behavior, offering significant contributions to ecological research and conservation. While challenges such as environmental factors and sensor limitations persist, continued advancements in UAV and sensor technology promise to enhance wildlife monitoring efforts. By combining thermal sensors with other sensor types, researchers can gather more precise and non-invasive data, supporting better wildlife management strategies and ultimately contributing to the preservation of endangered species (Gonzalez et al., 2017).

CONCLUSIONS

The study successfully achieved its objective of assessing the use of UAVs with thermal sensors to detect wildlife, particularly Komodo dragons. It was found that thermal sensors are more effective in the afternoon, as animals' body temperatures create a more noticeable contrast with the surrounding environment, making them easier to detect. The movement of animals between morning and afternoon further influenced thermal detection, underscoring the importance of proper timing in observations. Combining thermal and multispectral sensors proved to be crucial for overcoming challenges such as small temperature differences and environmental factors like fog or haze, which could otherwise hinder the accuracy of thermal detection.

This research fills an important gap in wildlife monitoring by demonstrating how UAVs can be effectively used to study species in their natural habitat without traditional ground surveys. The findings open new possibilities for non-invasive monitoring and conservation, especially for endangered species like the Komodo dragon. The study also paves the way for future advancements in UAV technology and multisensor integration, contributing to more efficient and precise ecological research and wildlife conservation efforts for the largest area.

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