Preliminary Design of an UAV Based System for Wildlife Monitoring and Conservation

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ABSTRACT

This paper presents the preliminary design of a drone-based wildlife monitoring and conservation system that aims to improve and enhance wildlife population monitoring and detect illegal activities in national parks across the globe. The proposed monitoring system aims to makes use of flexibility of drone-based systems to access remote locations and hazardous environments at a lower cost and overcome the limitations traditional methods such as ground surveys and manned aircraft. The system will be able to assist in monitoring wildlife populations and analysing current conservation efforts by providing trend analyses and play a very important role in identifying threats to the population and detecting illegal activities such as animal poaching and trespassing. The proposed UAV system is designed through a study of meteorological history of Koyna Wildlife Reserve in India and Sri Lanna National Park in Thailand as case studies. Results from the analysis indicate that the cost of implementation of a UAV based system would be approximately $7200 per system. The incorporation of Machine learning to streamline and enhance effectives of the UAV system has also been proposed in this paper.

Keywords: UAV, Wildlife Monitoring, Machine Learning

INTRODUCTION

Wildlife monitoring plays an important role when it comes to management, conservation, and analysis of wildlife populations of a given region. It allows for a better understanding of the current status of the eco system, and additionally assist in trend monitoring to detect earlier any challenges that may be faced.

Effectiveness of conservation efforts are mapped using specific information such as wildlife population trends, seasonal distribution, range, and movements which ultimately play an important role in adaptive management decisions regarding population management to ensure a healthy ecosystem [1]. This information is particularly crucial when it comes to the analysis of critically endangered species as the population pool is very small. If there is an upward trend in population size, the conservation could be deemed effective. However, if the opposite occurs, changes to the conservation efforts can be made quickly to improve the effectiveness of the measures that are put in place.

Thus, the tracking and analysis of wildlife populations is very crucial to understand the effectiveness of conservation methods. Drastic or alarming changes in population health or abnormal wildlife movement behaviours are some indicators that suggest that there might be a disease outbreak within the region, which may raise the need for intervention. Early intervention could potentially lead to effective early containment measures to be put in place, preventing spread to greater regions and populations. This could also potentially aid the prevention of human disease outbreaks [2]. Common viruses that originated from animals include but are not limited to Avian Influenza, SARS, and Ebola. Thus, early monitoring and effective conservation methods can play a crucial role in disease prevention in wildlife as well as human population. Active wildlife monitoring also plays a crucial role when it comes to the monitoring of the environmental health. Drops in population sizes, and abnormal migratory movements could suggest that presence of ecological imbalance or threats which might be an issue such as pollution, loss of habitat due to environmental disasters and drought. Wildlife monitoring assists in the early detections of such abnormalities, so immediate action can be taken to mitigate such issues.

Combatting illegal animal trade activities such as poaching is also crucial to the conservation of wildlife populations. In Asia, the demand for illegal wildlife products is driven significantly by the demand of illegal wildlife products or animals to be used as a display of social/economic status or for use in traditional medicine. The most common endangered species that can be identified as targets of such activities particularly in Asia include, but are not limited to, tigers, elephants, pangolins, and rhinos. The world's largest unregulated ivory market is in Thailand despite the species being revered as a culturally significant animal [3]. Majority of the abovementioned species are endangered, and their populations are very sensitive and are in dire need of growth with a 69% decrease in wildlife population from 1970 to 2018 [4]. This suggests that despite all the efforts that have been put in place over the past few decades to mitigate and minimise this, there is a significant decline in wildlife populations. Hence, an updated and effective monitoring system is the need of the hour to detect illegal poaching of endangered animals.

Wildlife monitoring is usually conducted using multiple methods. Some of which include [5]:

- Human Observation/Field Surveys
- Camera Traps
- Monitoring devices
- GPS microchipping for poaching
- Visual observation and satellite imagery for wildfire monitoring

Human observation and field surveys are conducted though direct or indirect observations of animals through their movement, faecal matter, or their tracks. However, this method requires large manpower to obtain effective and accurate analysis. Inaccessibility in remote regions and inclement weather severely impact human observations as well making it a very difficult method and time-consuming method for wildlife tracking [5], [6]. Utilisation of highly qualified manpower adds to the cost of tracking thereby severely impacting conservation efforts in regions with limited resources.

To track endangered species more accurately, or wildlife which are limited by the abovementioned factors, camera traps are one of the most effective and efficient modern method used. Camera traps work by using motion detectors which are triggered by passive infra-red sensors, which capture images or videos when movement is detected within range. This is highly beneficial as it omits the need for manpower to be physically present and can be operated remotely [5]. However, camera traps can only cover areas spanning between $10m^2$ to $20m^2$ making it very difficult to completely monitor very large areas [7] To overcome this issue, strategic placement of these cameras along commonly known frequented areas is common practice. A cluster of 100 cameras is commonly used with each camera costing about $400-700 making it an expensive method for wildlife monitoring [8].

Wildlife is also monitoring through GPS microchipping. GPS enabled tracking devices such as collar or tags are often attached to the animals to track their migratory movements, habitat selection patterns and daily movement patterns. However, there are several downsides to using this method including a detrimental effect on the movement and well-being of the animal. GPS enabled trackers resulted in an increased mortality rate by 16% and a decrease in reproduction by 39% [9]. GPS trackers are also used to monitor wildlife poaching. Microchips are usually placed on the more desirable parts of the animals for e.g., elephant tusks so that they can be tracked if such an activity were to occur. However, the microchips only act as a deterrent and can only be effective once the crime has been committed [10].

Wildfires tend to have a severe impact on the ecology of a nature reserve. Wildlife conservation also involves success in fire suppression. Examples of wildfire monitoring include watchtowers, imagery processing from satellites and aerial analysis through the means of aircraft [11]. Watchtowers can detect wildfires early but are limited in range and visibility. Satellite imageries are effective in detecting medium to large fires, but the frequency of imagery tends to be infrequent due to time lag and weather constraints such as cloud cover. Thus, aircraft are used to fill time gaps where satellite imagery cannot be used. However, for this to be done, there are several resources needed such as the availability of aircraft, infrastructure to accommodate aircraft and trained crew members. This would cause large costs to be incurred and would require a well-developed infrastructure.

Thus, for effective wildlife conservation to take place, it is essential to identify a low-cost solution that can cover a large area, provide real-time data and be non-invasive for animals. In this paper, the authors explore the feasibility of an UAV based system with the following design requirements:

- Must be able to monitor wildlife with minimal human interaction involved, reducing impact on the welfare and lifestyle of the animals involved.
- Possible implementation of machine learning (ML) to assist in actively identifying specific species to reduce the need for excessively large databases and reduction in analysis post monitoring.
- Assist in the detection of poaching or other illegal animal trade activity in a more active manner.
- Able to assist in early-stage wildfire detection.
- Assist in monitoring areas which are harder to reach on foot and operate both during the day and night.

METHODOLOGY

The methodology for this paper involves focusing on two nature reserves in India (Koyna Wildlife Sanctuary) and Thailand (Sri Lanna National Park) and conducting an operational environment analysis of these two nature reserves. The operational environment analysis will feed into the hardware analysis and selection of the proposed UAV system.

Introduction to Area of Focus

Koyna Wildlife Sanctuary:

Koyna Wildlife Sanctuary is located in the Satara district of Maharashtra, India. Its establishment was formalised in 1985 and is currently governed by the Maharashtra State Forest Department [12]. It lies within the Sahyadri mountain range and covers a land space of approximately $423.55\ km^2$ and is elevated approximately 600 to 1100 metres above sea level. The sanctuary was established as part of the UNESCO World of Biosphere Reserves in India in 2012 and plays an integral role in showcasing India's ecological biodiversity both regionally and worldwide. Furthermore, it consists of the eastern and western catchments of the Koyna Dam, which is part of the Koyna Hydroelectric Project, which is the largest completed hydroelectric power plant in India. Some of the endangered species that can be found within the region include but are not limited to are the Bengal Tiger, Indian Leopard, Indian Gaur, and the Malabar Giant Squirrel. However, there are many threats to this region due to tourism, implementation of windmills and land sales which has led to increased human activity in the region and in turn, habitat loss [13]. Hence, there is a crucial need to monitor and track the status and wellbeing of these animals to prevent them from going into extinction.

Sri Lanna National Park:

Sri Lanna National Park is in the Chiang Mai Province of Thailand and is the eight largest national park in the country. It spans across the Mae Taeng, Chiang Dao and Phrao districts and covers a land space of approximately $1406\ km^2$, with an altitude range of 400 metres at its lowest point, to 1718 metres above sea level at its highest peak at Doi Chom Hot. It was established in 1989 as Thailand's 60th National Park and consists of two main hill tribes, the Karen and Lahu tribes. Some of the endangered species that can be found in this region includes but is not limited to the Asian Elephant, Indian Gaur, Clouded Leopard, and Chinese Pangolin. Sri Lanna National Park is heavily reliant on tourism which is a natural threat of habitat loss from the need to convert land for the necessary infrastructure.

Fortunately, this impact has not been as significant as that of that in Koyna Wildlife Sanctuary. The main threat wildlife is this region comes from poaching and illegal wildlife trade. Hence, there is a need to combat this issue, along with the general monitoring of the wildlife in the region, to upkeep and improve the populations of the endangered species of the region to prevent the status of the species from being driven into extinction.

Operational Environment Analysis:

A detailed analysis of the operational environment will allow for better understanding of the potential hurdles that the design for the drone – based wildlife monitoring and conservation system should be able overcome to be effective. Furthermore, it will also provide a better understanding of the limitations of the system.

Rainfall Analysis of Operating Region

Since both Koyna Wildlife Sanctuary and Sri Lanna National Park are situated in tropical climates, the main source of precipitation within the environment would be from rain. According to Gao et al., this is the most limiting weather when it comes to drone operation [14]. Hence, the analysis of this factor would be crucial in obtaining a suited drone to be utilised within the system. Furthermore, the understanding of extreme weather conditions will also lead to a better gauge of the limits of the system, should it be implemented. Gao et al. suggested that utilising drones in unsuitable conditions with higher precipitation would not only affect the physical airworthiness of the drone, but also the internal components such as cameras, optical sensors, and other electronics.

Figure 1 describes the average monthly rainfall in both wildlife sanctuaries over a span of 11 years, from 2010 to 2020 based on the data provided was obtained via NASA's Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) project [15]–[17].

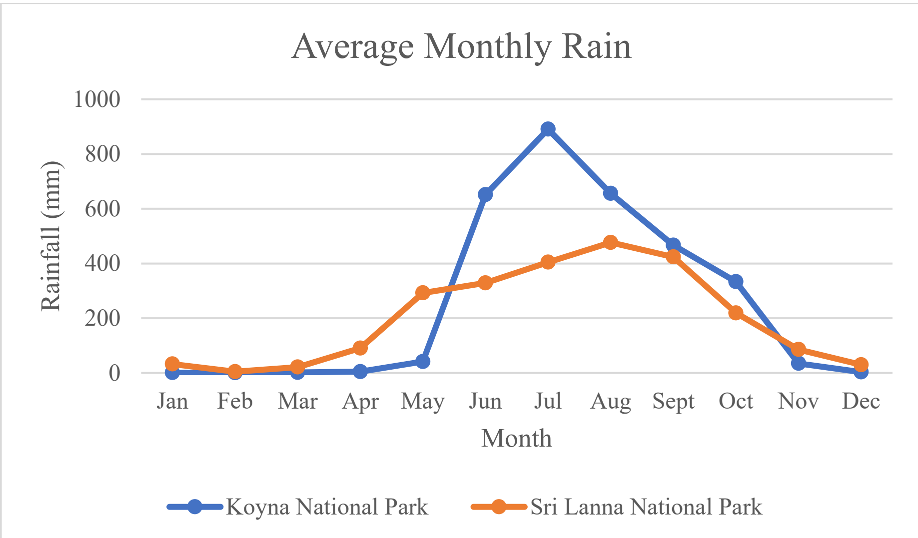

Figure 1: Average Monthly Rainfall

From the figure it can be observed that the amount of rainfall experienced in both regions peak during the monsoon season in between April and October. Thus, for the UAV system to be effective throughout the year, it must be able to withstand a continuous rainfall period from April to October. Hence, the primary design consideration is that drone and selected ancillaries selected for operation should be water resistant to prevent damage to the system prevent inoperability of the overall system during such periods.

Windspeed Analysis of Operating Region

The understanding of windspeed in the operating region is essential is also critical to prevent erratic or unstable behaviour from the drone. A poorly selected drone would result in blurry footage when capturing the necessary data. Also, operating at regions beyond the capabilities of the motors could potentially lead to further failures such as overheating in the motors or crash. Furthermore, understanding the operating environment will also provide a sense for viability for the potential implementation of a drone – based wildlife monitoring and conservation system and its limits in the two wildlife reserves involved.

Figure 2 shows the average monthly windspeed recorded at both Koyna Wildlife Sanctuary and Sri Lanna National Park over a span of 11 years, from 2010 to 2020 [15]–[17].

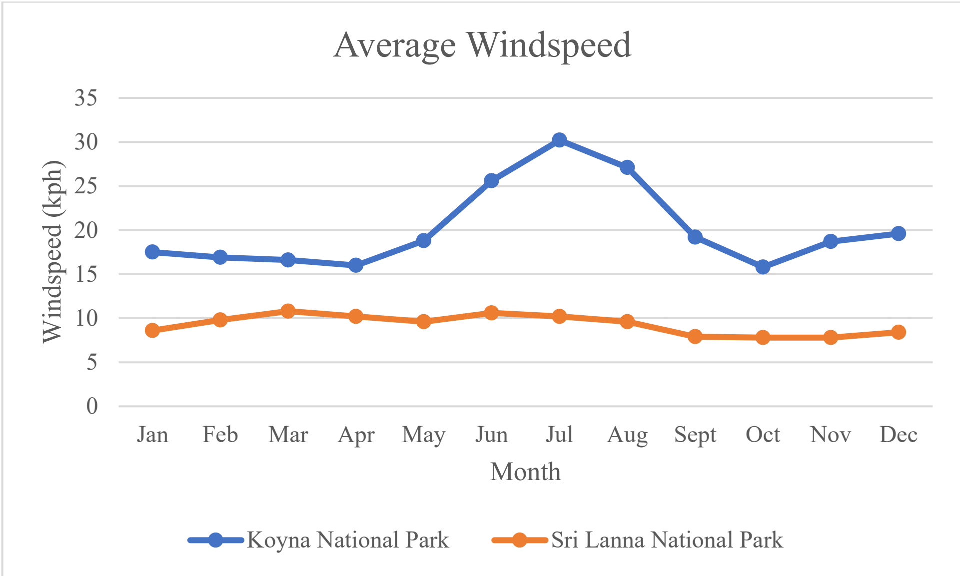

Figure 2: Average Windspeed

Figure 2 indicates that the peak windspeed for both wildlife sanctuaries occurs in July, specifically at Koyna Wildlife Sanctuary. Hence, since this study focuses on the use of a single system to be implemented into both sanctuaries, that would be used as a benchmark. The average windspeed for the two nature reserves falls under the Level 5 Beaufort Number category [18]. Therefore, a drone that is able to operate at this wind level and beyond would be required for the monitoring and conservation system.

Temperature Analysis of Operating Region

The environmental temperature is also an essential factor to consider during drone and component selection. Operation in extreme temperatures could potentially lead to significant effects on the battery life and performance of the drone [19]. Most modern drones utilise lithium-ion batteries as a power source. The performance of these batteries significantly decreases at lower temperatures, specifically at subzero temperatures [20]Although the operating regions for the drone system would be in a tropical climate, it is essential to do so to ensure that a drone with an appropriate operability range is selected. Figure 3 illustrates the average high and low temperatures of both national parks from 2010 to 2020 [15]–[17].

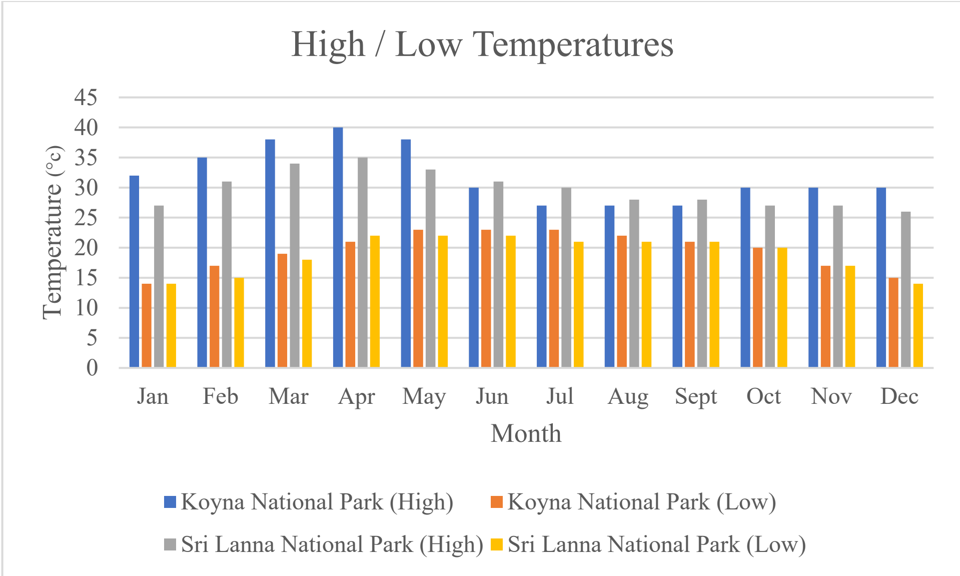

Figure 3: Temperature of Operating Region

From the figure it can be observed that the maximum temperature of $40°C$ was observed in April at Koyna Wildlife Sanctuary. Also, a minimum temperature of $14°C$ were observed at both reserves over several months. Therefore, the drone and the ancillaries to be utilised in this system would require to be operated within these temperatures to maximise operational efficiency of the overall system.

Camera and Miscellaneous Sensor Considerations

Successful monitoring and tracking of wildlife populations would require effective monitoring systems. The current main method of monitoring through the means of a camera will be the focus of further analysis, as there are distinct advantages of using camera-based monitoring systems [21]. Camera traps are non-invasive and does not affect animal behaviour. This is due to the camera trap being stationary not using any form of conventional flash when capturing imagery. Being able to operate with minimal effects to the livelihood and welfare of the wildlife involved is crucial and should be a key factor of consideration during implementation.

Therefore, the proposed drone – based system could be designed to operate from a distance, rather than a closer proximity to mimic this plus point. However, to do so, it would require a means of capturing the presence of wildlife from a further distance. This could be easily achieved through the utilisation of a camera with excellent zoom options. However, with standard digital zoom, the images that are captured by the camera are usually enlarged through the means of signal processing, which in turn results in a reduction in image quality due to these signals being estimated [22]Hence, a drone which supports a suitable camera to process high quality imagery is essential to compensate for the drop in quality when digital zoom is to be utilised.

In terms of camera and sensor considerations, the main hurdle that the drone – based wildlife monitoring and conservation system needs to overcome is the restriction due to operational environments involved. Both wildlife sanctuaries are made up of densely populated forests which is a hindrance to the operation of the drone. Thus, the inability of the drone to access certain areas to due to such restrictions such as dense vegetation cover would render the proposed system to be inefficient to detect the presence of certain wildlife. Additionally, nocturnal creatures, which are not active during the day also would also not be detected due to poor camera sensors for night monitoring.

Therefore, the proposed drone system should make use of thermal cameras. The use of thermal cameras has deemed to be successful in the detection of three different mammal species in similar operational environments in rainforests in Barro Colorado Island, Panama [21]. It was found to be extremely effective during night and early mornings. However, issues did arise when the temperature of the operational environment increased, making detections less obvious, and hence, less effective. This suggests that reliance on thermal imagery alone would be insufficient, especially during the day. However, its effectiveness during the night and areas with restricted daylight still would make it a key implementation for operability. Therefore, there is a need to utilise traditional RGB camera imagery as proposed in conjunction with thermal cameras for the system to be effective and operational around the clock to assist in wildlife detection.

Additionally, the use of infrared imaging through the means of thermal cameras have been deemed beneficial for other aspects of proposed system. Thermal cameras can be used to identify hotspots and assist in the sensitive detection of holdover fires, prior to build up, that may not be as easily detected by traditional RGB imaging [11]. Early detection of potential fires is crucial as it could potentially prevent fire outbreaks, which could be detrimental to the environment. Furthermore, in the case fire outbreaks, thermal imagery could be used to assess the fire more accurately as it would be able to work despite visible obstructions such as smoke. This would allow firefighters to effectively assess and combat the fire more strategically, hence reducing the amount of damaged caused to the environment.

Thermal imaging has also been successful in detection of poachers in Southwest Africa [23]. Handheld Infrared Thermography units were successfully utilised to detect poachers who were visibly hidden in bush cover. This suggests that the use of such technology would be useful in combatting illegal wildlife activity if extended to the proposed drone – based system. Furthermore, as previously discussed, the use of thermal imagery tends to be highly effective during the night due to the lack of environmental heat. This would be additional point to incorporate thermal imagery as most poaching occurs at night.

RESULTS

Proposed Drone Solution

Based on the Operational Environment Analysis, the minimum drone requirement is as follows:

- Ability to operate in Level 5 Beaufort Number category of winds.
- Water resistance to be utilised during the monsoon seasons.
- Operational temperature range limit of $14°C - 40°C$.
- Ability to detect animal movements in thick canopy and remote regions and detection of animal type in day and night.
- Strong lossless zoom capabilities

Therefore, based on these design requirements, an appropriate drone selection can be determined based on a primary market research. The DJI Mavic 2 Enterprise Advanced (M2EA) is found to be an excellent choice [24]. The M2EA drone was utilised in the development of a method to automate the detection of animals through the means of utilising both drone and camera trap data by Liverpool John Moores University [25] . The uses of the drone during this development were very similar to what needed for the current proposed drone – based wildlife monitoring and conservation system. The drone's thermal capabilities were also analysed through the means of detecting wildlife such as rhinos and baboons. Also, the M2EA was utilised and deemed successful in the detection of fires in Indonesia and assisted in the detection of poachers in Kenya [25]. Additionally, a predecessor of the M2EA was also successfully utilised to aid in the detection of spider monkeys, while only using RGB camera capabilities [26]. Since both the thermal and RGB cameras of the M2EA have been tested and proven within similar use cases, the utilisation of the drone for the purpose of the proposed drone – based system would be ideal as it would be of minimal risk. The cost of the M2EA is approximately $7094 USD [25]

The M2EA is equipped with a 640×512 px radiometric thermal sensor, which is a capable of operating at 30Hz with $16 \times$ digital zoom [24]. This is in line with the minimum drone design requirements. Also, for traditional RGB imagery hardware, the drone is equipped with a 48MP visual camera, with $32 \times$ digital zoom, which also support ultra zoom. This would allow the drone to operate from a fair distance away from wildlife, hence reducing the obstructions caused to the animals during operation.

The drone has a maximum flight time of approximately 31 minutes, with a transmission range of $10\ km$ and a surveillance area of $2\ km^2$. This would allow the system to be utilised over a wide area for a suitable time duration for data collection during each flight. Additionally, it has a maximum wind speed resistance of $10\ m/s$, which allows it to be operable within Level 5 Beaufort Number category of winds. Furthermore, the M2EA is equipped with a RTK module, along with standard GNSS systems, which would make it capable of operating with high levels of accuracy. This is essential as for the proposed drone – based system, the accurate determination of positions of wildlife, fires and/or poachers would be crucial for a more efficient response.

The operating temperature range of the M2EA is from $-10°$ to $40°$, which allows it to be operable even during seasons when extreme temperatures are observed within the two regions in focus. However, the one downside of the proposed drone is that it is not certified to be water resistant. However, there is a way to overcome this issue. Third party wet suits such as those developed by Phantom Rain would allow the M2EA to operate in more severe conditions as it provides protection to vital and moisture sensitive components such as the battery and power button [27]. The M2EA makes use of aluminium brush-less motors, that can operate despite the presence of moisture and hence displaying a level of water resistance. The cost implementation of the wet suit is approximately $94.95 USD, which is only a small fraction of the total cost of the drone.

Incorporation of Machine Learning

Images and videos collected from the M2EA (or a suitable alternative) can be used to train ML algorithms to improve wildlife identification accuracy. ML can potentially be used to aid in the detection of specific species while operating the drone – based wildlife monitoring and conservation system. This will not only assist the user significantly in terms of real – time detection but could also be used to reduce the amount of excess data stored significantly within databases. Mitigation and minimisation of data pile up is possible using deep learning. Deep learning has proven to assist in automating the detection and identification of 99.3% of a 3.2 million large image data set with an accuracy of 93.6% [28]. Through resource reduction involved in data post – processing using deep learning, it would be possible to allocate more resources more important aspects that could directly aid in the monitoring and conservation of wildlife. The accuracies produced by human volunteers manually during similar classifications are estimated to be approximately 96.6% and 90.0% for species and count labels respectively [28]. This is significant as prior automated system did in fact produce more accurate and consistent results. This suggests that the implementation of a similar concept into the drone – based wildlife monitoring and conservation would increase the accuracy and efficiency of the overall system beyond average human capabilities.

Further uses of machine learning could be implemented to the system such as to aid in the detection of weapons or objects that are commonly used while performing illegal wildlife activities such as guns or tranquilizers. A possible alert could be sent if such features were to be picked up on camera. However, this is a possible implementation for the future once the base system has been deemed successful and proven.

The authors made use of a pre-collated dataset to train and test the implementation of ML for wildlife conservation [29]. Preliminary tests were conducted using pigeons to understand the accuracy of the ML model. The ML model was created and tested within Google Colaboratory and the model was trained through the utilisation of YOLOv8 [30], [31] .

Conditional results depicted in indicate that the ML model produced satisfactory results as a proof of concept. While, in some cases the accuracy of identification was as low as 42%, further training of the model with a larger dataset would enhance accuracy.

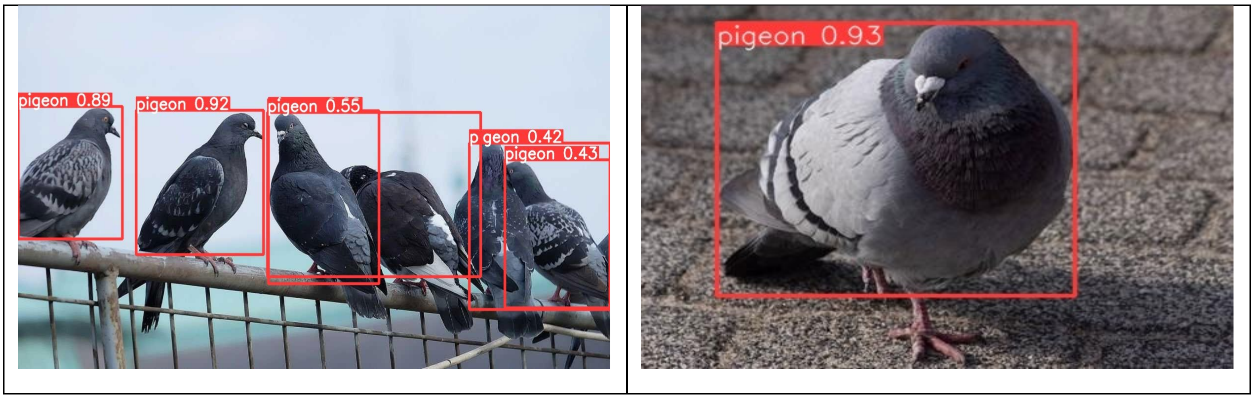

Figure 4: Examples from image testing for the ML model

Thus, the use of ML can faster identification of animals and aid the drone/UAV based system for wildlife conservation and management.

CONCLUSION

In this paper, the importance of wildlife monitoring and conservation for wildlife management were discussed. Through this, conservatories are able to monitor the effectiveness of measures that are currently in place and adjust them accordingly. Furthermore, commonly used methods of doing so have been thoroughly analysed, from which their strengths and weaknesses have been highlighted.

Despite the wide array of methods that have been implemented, the threat of extinction of wildlife species is still on the rise in recent years. Therefore, an UAV-based wildlife monitoring and conservation system was proposed to fill in the gaps and further improve on aspects of traditionally used means of monitoring and conservation. Furthermore, the possible proposal and methods to extend the system to aid in combatting illegal wildlife activities and assist in wildfire detection were highlighted.

The potential environmental challenges of the Koyna Wildlife Sanctuary and Sri Lanna National Park was analysed to obtain a more detailed design requirement suitable for the proposed operational regions.

It was found the proposed drone would require to be operational at Level 5 Beaufort level winds, in temperatures ranging from $14 - 40^{\circ}C$, a monsoon season lasting from April to October and the ability to track wildlife at any time of the day. Based on these specifications, a suitable drone model was proposed with a total preliminary cost of implementation of approximately $7190 USD. A preliminary test to incorporate machine learning to detect wildlife was conducted and the trained model had a confidence level ranging from 42%-93%. Further training of the model would result in accurate image recognition and reduction in data processing times thereby making the UAV-based wildlife monitoring and conservation system a practical choice for implementation in inaccessible regions with inclement weather.

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