Investigating The Impact Of Distance On Object Detection Accuracy in Unmanned Aerial Vehicle Systems Using MobileNetV3

Mallikarjun Bhusnoor 1, Jyoti Patel 1, Akshara Mehta 1, Sandeep Sainkar 1, Dhrumil Patel 1, and Ninad Mehendale 2

1Affiliation not available
2Somaiya Vidyavihar University

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Abstract

This study investigates the feasibility of using Raspberry Pi-equipped Unmanned Aerial Vehicles (UAVs) for object detection. The research focuses on analyzing the impact of the distance between the UAV and the target person on the accuracy of object detection. Experimental results reveal a decrease in detection accuracy as the distance between the UAV and the target person increases, emphasizing the critical role of distance in efficient object detection systems. By combining drones, Raspberry Pi, and machine learning algorithms, this research showcases the potential of advanced object detection systems. The findings contribute to the growing application of UAV technology by refining and optimizing UAV-based object detection systems.
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Index Terms—Unmanned aerial vehicles (UAVs), Object detection, Raspberry Pi, MobileNetV3

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have emerged as powerful tools with diverse applications in various fields, revolutionizing data collection and analysis. Industries such as urban planning, agriculture, forestry, and surveying have benefited from the versatility of UAV technology.

This research paper aims to harness the potential of UAVs, particularly in the context of object detection, to enhance efficiency and accuracy in this critical task. Leveraging the integration of drones with Raspberry Pi technology has further propelled advancements in data processing and analysis.

In particular, the combination of drones, Raspberry Pi, and machine learning algorithms has shown significant promise in improving object detection performance. By equipping UAVs with Raspberry Pi devices for onboard image processing, this project endeavors to develop an advanced object detection system.

Traditional object detection methods often encounter limitations in terms of coverage and accuracy. However, the utilization of drones with high-resolution cameras, along with the processing capabilities of Raspberry Pi, enables efficient capture of images and videos over large areas, facilitating real-time object detection.

The onboard Raspberry Pi empowers rapid and precise analysis of the collected data, enabling the system to efficiently identify and classify objects with increased accuracy.

Overall, this research contributes to the growing potential of UAV technology by refining and optimizing object detection systems. The combination of drones and Raspberry Pi presents new opportunities for enhanced object detection, paving the way for practical implementations in various industries and applications.

Traditional methods of object detection often encounter limitations related to coverage and accuracy[11]. By utilizing drones with high-resolution cameras and Raspberry Pi devices, we can efficiently capture images and videos of large areas, facilitating real-time object detection. The onboard Raspberry Pi empowers rapid and precise analysis of the captured data, enabling efficient identification and classification of objects.

Central to the success of the object detection system is the utilization of machine learning algorithms. These algorithms are trained on diverse datasets, enabling them to recognize and differentiate various object categories, such as vehicles, pedestrians, or specific items of interest. The amalgamation of drones, Raspberry Pi, and machine learning algorithms paves the way for an advanced object detection system with enhanced accuracy and efficiency.

The research at hand draws inspiration from relevant studies conducted in the field of object detection in UAV-based images. This particular area of study presents significant challenges and holds great potential for applications such as surveillance, search and rescue operations, and environmental monitoring. Deep learning techniques have played a transformative role in advancing the field of object detection and tracking.

Zhou et al. [11] address the specific challenge of detecting small objects in UAV-based images by introducing a distance metric method. Their approach utilizes deep learning techniques to accurately identify and localize small objects, effectively addressing issues related to scale variations and limited resolution.

In a similar vein, Wu et al. [12] contribute to this field through a comprehensive survey that focuses on deep learning-based approaches for object detection and tracking in UAV scenarios. Their survey encompasses a wide range of state-of-the-art techniques, including network architectures, training strategies, and performance evaluation metrics.

By leveraging the insights gained from these studies, our research project aims to contribute to the growing potential of...
II. METHODOLOGY

This research employs a systematic approach to achieve the objectives of developing a UAV-based object detection system. The methodology encompasses the hardware and software setup, the establishment of wireless connectivity between the UAV and Ground Station, and the implementation of the object detection algorithm on Raspberry Pi. The step-by-step process for the successful integration and functioning of the system is elucidated below:

A. Hardware Setup:

The UAV is equipped with a high-resolution camera to capture images and videos during flight. We use a Raspberry Pi onboard the UAV as the processing unit to handle the real-time analysis of the collected data. The Raspberry Pi is configured with the necessary components, including a compatible camera module and connectivity interfaces.

B. Software Setup:

For the object detection algorithm, we employ state-of-the-art machine learning techniques, specifically deep learning-based models, to achieve accurate and efficient detection. The selected model is MobileNetV3, known for its lightweight architecture, making it suitable for onboard processing on Raspberry Pi.

C. Wireless Connectivity:

To enable real-time communication and data transfer between the UAV and the Ground Station, a reliable wireless connection is established. We employ standard communication protocols, such as Wi-Fi or radio transmission, to ensure seamless data exchange.

D. Object Detection Algorithm Implementation:

The object detection algorithm, based on the selected MobileNetV3 model, is implemented on the Raspberry Pi. We utilize popular machine learning libraries, such as TensorFlow or PyTorch, to implement and train the model. The model is trained on diverse datasets, allowing it to recognize and differentiate various object categories.

E. Calibration and Testing:

Calibration of the hardware components is performed to ensure precise data capture and accurate processing. The UAV is flown over various environments, capturing images and videos of different objects, including vehicles, pedestrians, and other objects of interest. The performance of the object detection algorithm is thoroughly evaluated on these test datasets.

F. Data Analysis and System Integration:

The collected data is processed and analyzed on the Raspberry Pi in real-time. The object detection algorithm identifies and localizes objects in the captured images and videos, generating bounding boxes and corresponding confidence scores.

G. System Integration:

The components of the UAV-based object detection system are integrated into a cohesive unit. We ensure that the UAV, Raspberry Pi, and object detection algorithm work harmoniously, enabling efficient and reliable object detection during flight.

H. Performance Evaluation:

The performance of the developed UAV-based object detection system is evaluated using appropriate metrics such as accuracy, precision, recall, and processing speed. Comparative analysis with existing object detection methods and baseline results are conducted to assess the system’s effectiveness.

Through this comprehensive methodology, we aim to establish an advanced UAV-based object detection system that enhances accuracy and efficiency, paving the way for practical implementations in various applications, such as surveillance, security, and environmental monitoring.

III. DRONE COMPONENTS

A. Brushless DC (BLDC) Motors

BLDC Motors, as the name implies, they do not have any brushes and copper commutator. In Figure 1 we can see a 920kv motor having 3 soldered wires with phases A, B and C. It has good efficiency, i.e., they can be operated at maximum torque over a continuous period of time and they have good controllability because of precision based control which in turn reduces the battery consumption thus lengthens the battery time or flight time. In this research we have used 920 KV BLDC motor which means motor will rotate at approximately 920 RPM when supplied with a voltage of 1 volt.

![Fig. 1. 920 KV BLDC Motor [20]](image-url)
B. Electronic Speed Controller

Electronic Speed Controllers (ESCs) are devices that incorporate circuits designed to regulate the speed of motors in a UAV. By individually controlling the speed of each motor, the ESCs play a crucial role in determining the maneuverability and stability of the drone. These devices adjust the power and timing of the electrical signals supplied to the motors, enabling precise control and coordination, which directly impact the drone’s flight characteristics and overall performance. Electronic Speed Controllers (ESCs) are devices that incorporate circuits designed to regulate the speed of motors in a UAV. By individually controlling the speed of each motor, the ESCs play a crucial role in determining the maneuverability and stability of the drone. These devices adjust the power and timing of the electrical signals supplied to the motors, enabling precise control and coordination, which directly impact the drone’s flight characteristics and overall performance. In this research we have used 30A ESC as shown in Figure 2. When paired with a 920kV motor, which generally operates at higher power levels, the 30A ESC can effectively manage the electrical current flowing through the motor. This ensures reliable and efficient performance without the risk of overloading the ESC.

C. Propellers

Propellers are essential components of a drone that convert the rotational motion of the motors into linear thrust. This thrust is responsible for lifting the UAV against the force of gravity. Figure 3 shows a propeller with blades, these propeller blades generate lift force due to a difference in pressure between their upper and bottom surfaces. As the propeller spins, it accelerates the surrounding air, creating a downward flow of air and an upward force that counters the force of gravity, allowing the drone to stay airborne.

D. Drone Frame

The drone frame used in this research is S500 quadcopter frame which is entirely made up of carbon fiber and as Carbon fiber is known for its exceptional strength-to-weight ratio. As we can see in Figure 4, the S500 frame has a symmetric design of a quadcopter. It is significantly lighter than materials such as aluminum or steel, which translates to reduced overall weight for the drone.

E. Pixhawk

The Pixhawk is an open-source flight controller specifically designed for Unmanned Aerial Vehicles (UAVs). Figure 5 depicts the pixhawk flight controller’s front view, which includes a number of connection ports. It boasts a robust hardware design and supports a wide array of sensors, including GPS, accelerometers, gyroscopes, magnetometers, and barometers. This sensor suite enables precise and reliable navigation and flight control. In our research, we are utilizing the Pixhawk 2.4.8 variant. This version offers specific specifications such as 512kb of RAM, 2MB of flash drive storage, and a 32-bit ARM Cortex-M4F processor. It operates within a voltage range of 4.3V to 5V.

F. Battery

Lithium polymer batteries, commonly referred to as LiPo batteries, serve as the primary energy source for drones. These batteries are renowned for their lightweight nature, high energy density, and impressive discharge rate. In this research we are utilizing a 2200mAH Lithium-Polymer rechargeable battery to meet our objectives. Figure 6 shows that the battery contains two cables with end ports. When linked to the pins of a multimeter, the JST-XH port is used to monitor the voltage of the battery while the XT60 port is used to connect the battery to the power supply board.
G. Power Module

The power module is a crucial component in a drone system, responsible for managing power distribution and regulation. It addresses the differing voltage requirements of the Pixhawk flight controller and ESCs by offering separate outputs. It has 3 wired ports as seen in Figure 7. The Pixhawk operates at 5V, necessitating a dedicated power supply to ensure optimal performance and effective communication with peripherals. The power module meets this requirement by providing a 5V output directly to the Pixhawk.

In contrast, the ESCs typically operate at 12V for efficient motor control. To cater to this need, the power module supplies a separate 12V output designed specifically for the ESCs. This enables them to regulate and control the power sent to the motors, ensuring reliable and responsive performance.

By providing distinct power outputs for the Pixhawk and ESCs, the power module ensures that each component receives the appropriate voltage level essential for its operation. This segregation of power sources allows for smooth and efficient functioning of both the flight controller and motor control system, contributing to overall drone performance and stability. Without this segregation, incompatible voltage levels could result in component failure or erratic behavior. Hence, the power module plays a critical role in facilitating reliable power distribution and regulation within the drone system.

H. GPS

Figure 8 shows External GPS unit which is commonly used with Pixhawk flight controllers for improved accuracy and reliability. Despite Pixhawk having its own compass, external GPS units offer higher-quality sensors and antennas, resulting in better positioning data. They provide redundancy in case of internal GPS failure or signal interference, ensuring flight safety and stability. In this research, the NEO M8N GPS module was utilized, known for its high accuracy and ability to track multiple global navigation satellite systems (GNSS) like GPS, GLONASS, and Galileo.

I. Raspberry pi 4

The Raspberry Pi 4 is a powerful and versatile single-board computer. It offers improved performance and enhanced capabilities compared to its predecessors. With a quad-core ARM Cortex-A72 processor, increased RAM options, and support for dual 4K displays, the Raspberry Pi 4 is an excellent choice for various applications, including IoT projects, robotics, home automation, and DIY computing projects. In this research we have used Raspberry 4 for executing fire detection algorithm, thus Raspberry Pi 4 in this research acts as the primary processor. As seen in Figure 9 it looks like a mini mother board of a PC.

Object Detection using Raspberry pi
Object detection plays a crucial role across a range of applications, including surveillance, security, autonomous vehicles, and robotics [12][13][14]. However, conventional object detection methods often encounter limitations in terms of coverage and accuracy. Fortunately, the integration of drones and Raspberry Pi technology with advanced image processing capabilities presents a promising solution to overcome these challenges.

Equipped with high-resolution cameras and onboard Raspberry Pi devices, drones efficiently capture images and videos of expansive areas, enabling real-time object detection. Leveraging the processing power of Raspberry Pi, these drones perform swift and precise analysis of the captured data, facilitating efficient identification and classification of objects. Furthermore, the integration of machine learning algorithms elevates the object detection process to a new level. Through training on diverse datasets, these algorithms learn to discern various objects with remarkable accuracy [12][13]. As a result, the system becomes adept at distinguishing between different object categories, such as vehicles, pedestrians, or specific target items.

This integrated approach offers numerous advantages. It enables rapid and comprehensive coverage of large areas, making it highly suitable for applications like aerial surveillance, search and rescue missions, and critical infrastructure monitoring. Moreover, processing data directly onboard the drone reduces reliance on external computational resources and empowers real-time decision-making.

**J. Proposed System**

The proposed system comprises several components that work synergistically to enable efficient and accurate object detection using a UAV (quadcopter) as the platform. At the heart of the system is the Pixhawk flight controller, which serves as the central control unit for the drone. It provides stability and control during flight, ensuring smooth and precise maneuvers.

To address the challenge of vibrations that commonly occur during flight, a shock absorber mechanism is employed to securely mount the Pixhawk controller on the drone. This reduces the impact of vibrations on the controller’s performance, allowing for more reliable and accurate operations.

Underneath the drone, a Raspberry Pi board is installed as an onboard computer. The Raspberry Pi acts as the processing unit, hosting the object detection code. Its computational power and versatility make it an ideal choice for running sophisticated algorithms required for object detection tasks.

For capturing visual data, a Pi camera is strategically positioned on the front side of the drone. The camera provides a high-resolution feed of the drone’s surroundings, enabling the object detection algorithm to analyze the captured images in real-time.

Wireless communication between the drone and a ground station is established using telemetry modules. This wireless connection allows for seamless and immediate transmission of data between the drone and the ground station. It enables the retrieval of essential metrics and readings from the drone, including altitude, pitch, and yaw. These metrics are invaluable for evaluating the accuracy of object detection, particularly in scenarios where the distance between the drone and the objects of interest varies.

By integrating these components, the proposed system creates a robust and efficient framework for object detection using a UAV. The combination of the Pixhawk flight controller, shock absorber mechanism, Raspberry Pi onboard computer, Pi camera, and wireless telemetry modules facilitates real-time data processing, accurate object detection, and precise flight control. This system holds significant potential for various applications, including surveillance, search and rescue operations, and environmental monitoring, where accurate and efficient object detection is crucial.

The system shown in Figure 10 holds significant potential for various applications, including surveillance, search and rescue operations, and environmental monitoring, where accurate and efficient object detection is crucial.
K. Hardware Connection

Firstly, a Lipo battery serves as the primary power source for the drone. The battery connects directly to the drone’s power distribution board, which distributes power to all the Electronic Speed Controllers (ESCs). To regulate the current from the Lipo battery, a Power Module is employed. This module features two output wires, with one delivering a 12V output to the power distribution board for the ESCs, and the other providing a 5V output specifically for the Pixhawk flight controller. This ensures that the Pixhawk operates at its required voltage level. Figure 11 shows the top view of our proposed system.

Beneath the drone, a Raspberry Pi (RPi) is securely attached. The RPi is powered separately using a power bank, which supplies a stable 5V/3A output, ensuring sufficient power for the RPi’s operation. We can see the arrangement of RPi in our proposed UAV system from Figure 12. The RPi serves as an onboard computer and is connected to a Pi camera, enabling the capture of high-quality visual data for object detection purposes.

To establish wireless communication between the drone and the ground station, telemetry modules are utilized. The receiver module is connected to the ground station, while the transmitter module is attached to the Pixhawk flight controller, specifically in the TELEM port. This wireless connection facilitates the transfer of important data and metrics between the drone and the ground station, enabling real-time monitoring and control of the UAV. ESCs are connected to the “main out” pins of Pixhawk (as seen in Figure 13). Figure 14 shows connection of Essential components like battery, switch and GPS to the ports on Pixhawk.

Overall, these hardware connections form a robust and integrated system for the proposed drone setup. The Lipo battery powers the drone, the Power Module ensures appropriate voltage distribution, the RPi acts as an onboard computer, and the telemetry modules enable wireless communication with the ground station.

IV. Result

The aim of this study is to examine the correlation between the confidence percentage (accuracy) of object detection and the increasing distance between a UAV and a target object. The target object in this research is a person, and the distance between the object and UAV was systematically increased at intervals of 5 meters, starting from 5 meters and reaching up to 25 meters.

At the beginning of the experiment, the drone remained stationary while the target person was positioned at a distance of 5 meters from the drone as shown in Figure 16 and Figure 17.

Upon turning on the Raspberry Pi, its inbuilt WiFi feature seamlessly connected to a phone without any manual intervention. This wireless connection allowed for communication and data transfer between the Raspberry Pi and the phone. By leveraging the Raspberry Pi’s WiFi capability, the need for additional external networking equipment or configuration was eliminated. This simplified setup and automatic connectivity streamlined the process and facilitated efficient data exchange between the Raspberry Pi and the phone, enhancing the overall usability and convenience of the system.

To perform object detection on the Raspberry Pi, it is necessary to install essential libraries such as OpenCV, matplotlib, TensorFlow, among others. Once these libraries are installed, the detection scripts can be executed. To run the Python code, a Python IDE like Thorny, which is the default IDE installed on the Raspberry Pi, needs to be opened. When the Python code is executed, the camera is activated and begins capturing frames. These frames are then passed to the loaded detection model, which quickly predicts the objects it has been trained for. An output window is displayed on the screen, showing the image feed and the ongoing detection process, along with confidence scores. During the drone’s mission, as it takes off and progresses, it captures frames, and the model detects the objects present within them. This methodology enables the drone to be utilized for object detection or similar applications.
Following the initial distance of 5 meters, we proceeded to observe and measure the confidence percentage of object detection for the target person at subsequent intervals of 5 meters. These intervals included distances of 10 meters, 15 meters, 20 meters, and finally 25 meters as shown in Figure 17, Figure 18, Figure 19 and Figure 20. By systematically increasing the distance between the UAV and the target person, we were able to gather data on the variations in object detection confidence percentages at different distances, contributing to a comprehensive analysis of the relationship between distance and accuracy in our study.

Table 1 presents the relationship between distance (in meters) and the corresponding confidence percentages obtained for object detection. As the distance increased from 5 to
25 meters, the confidence percentage decreased gradually. Specifically, at a distance of 5 meters, the confidence percentage was 77.1%. However, as the distance increased to 10 meters, 15 meters, 20 meters, and 25 meters, the confidence percentages decreased to 55.23%, 44.1%, 36.37%, and 33.28% respectively. This data indicates a negative correlation between distance and object detection confidence percentage, suggesting that accuracy decreases as the UAV-to-target distance increases.

Figure 21 illustrates the correlation between distance, measured in meters, and the associated confidence scores derived from object detection. As the distance between the UAV and the target object increases, a clear downward trajectory in confidence scores is observed. Starting at an initial distance of 5 meters, a relatively high confidence score is registered, gradually diminishing with greater distances. At 10 meters, a notable drop in confidence score becomes apparent, followed by further declines at 15 meters, 20 meters, and 25 meters. This pattern suggests that as the UAV moves farther away from the target object, the object detection algorithm’s predictive certainty diminishes, leading to lower confidence scores. The graphical representation effectively showcases the inverse relationship between distance and confidence scores in the object detection process.

V. CONCLUSION

This research successfully involved the development of a drone specifically designed for object detection purposes where pixhauk was used as flight controller and Raspberry Pi as an on board computer. Through systematic experimentation, we analyzed the relationship between distance and accuracy in object detection using this drone. By increasing the distance between the UAV and the target person in 5-meter intervals, we observed a gradual decline in the confidence percentage of object detection. These results emphasize the significance of considering distance as a critical factor in designing efficient and reliable object detection systems utilizing UAV technology. Further advancements in detection algorithms and technological enhancements could contribute to improving the accuracy of object detection, especially at longer distances. This research lays the foundation for future investigations aimed at refining and optimizing UAV-based object detection systems.

VI. COMPETING INTERESTS

The authors declare that there is no competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

VII. REFERENCES


Sandeep Sainkar Dr. Sandeep Ramesh Sainkar is working with KJSCE since July 2007. Presently he is faculty in the Department of Electronics and Telecommunication Engineering. He completed his graduation (B.E.) in Electronics from Vivekananda Education Society’s Institute of Technology, Mumbai, Maharashtra in 2002, post-graduation (M.Tech.) (Electronics) in 2011, and PhD. in Electrical Engineering from Veermata Jijabai Technological Institute, Mumbai in 2022. He has more than sixteen years of experience in the teaching field. His research interests include Electromagnetics, RF Electronics, Microwave Devices, and Microstrip Antennas. He has actively participated in a few sponsored research projects on microwave passive and active devices. He is a Life Member of ISTE and an Associate Life Member of IETE.

Ninad Mehendale Dr. Ninad Dileep Mehendale is an Associate Professor in the Electronics Department at K. J. Somaiya College of Engineering. He holds a post-doctoral degree from the Karlsruhe Institute of Technology in Germany and has a Ph.D. in Microfabrication and Image Processing from the Indian Institute of Technology Bombay. He has expertise in various fields such as sound signal processing, machine vision, embedded systems, microfluidics and microfabrication, robotics, deep learning, and AR-Virtual Reality technology. He has won several awards, including a gold medal during his M-Tech. at NMIMS University and a Ratan Tata scholarship for being the highest-scoring student in MSBTE diploma exams. Dr. Mehendale is currently consulting several industries and institutions. Dr. Ninad is also working on many projects related to autonomous systems and artificial intelligence based projects.