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Innovation of Optical Sensor-Based Autopilot System for Real-Time Obstacle Detection on UAV

Indah Setya Khinanti[1], Indah Kumala Santi[1], Syakila Lathifa Rihan[1]

[1]*Physics Education, Faculty of Teacher Training and Education, University of Riau, Indonesia*

Corresponding author's email: indahsetya@gmail.com

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Abstract- The development of UAV (Unmanned Aerial Vehicle) technology demands improved navigation capabilities and automatic obstacle avoidance to improve operational safety and effectiveness. This research proposes an innovative optical sensor-based autopilot system capable of detecting obstacles in real-time on UAV. The system uses optical sensors combined with image processing algorithms to recognize and measure the distance of objects around the UAV, so it can make automatic navigation decisions such as changing flight direction to avoid collisions.) capable of detecting and avoiding obstacles in real-time. This system integrates RGB cameras and LiDAR sensors, which work synergistically to capture visual information and depth data of the surrounding environment. The data processing is carried out through image processing and sensor fusion algorithms, as well as the application of SLAM algorithms for mapping and navigation. The combined use of RGB cameras and LiDAR has been proven to improve accuracy, resilience to environmental conditions, and stability of UAV flight paths. This system has the potential to be a more adaptive and intelligent alternative solution compared to conventional autopilot systems, especially in environments without GPS signals..

Keywords: optical sensor,autopilot system, real-time obstacles, image processing

1 Introduction

An Unmanned Aerial Vehicle (UAV) is an unmanned aircraft that can be controlled automatically or remotely. Unmanned Aerial Vehicles (UAV) have an increasingly important role in various sectors, such as transportation, surveillance, agriculture, and the defense industry (Zhang & Kovacs, 2012). As tools operating in complex airspace, aircraft and UAV face various safety challenges, especially in detecting obstacles in their surroundings (Debnath et al., 2024). One crucial aspect in aircraft and UAV operations is the ability to detect and avoid obstacles in real-time, which requires an accurate, fast, and reliable system (Shang & Shen, 2019).

Currently, UAV autopilot systems such as accelerometers and gyroscopes are used to measure the drone's translational and rotational acceleration, thus helping determine the UAV attitude and movement internally. However, these sensors are unable to detect external obstacles around the drone (Smith, 2020). Magnetometers or digital compasses provide directional information relative to the Earth's magnetic field, but these sensors are susceptible to electromagnetic interference from drone components such as motors and ESCs, which can reduce the accuracy of directional readings (Johnson & Lee, 2019). Barometers are used to measure air pressure to determine flight altitude, although these sensors are sensitive to changes in weather and environmental pressure, which can cause inaccuracies (Wang et al., 2021). Additionally, wind speed sensors, such as pitot tubes, are commonly applied to fixed-wing drones to measure airspeed, but are less effective in multi-rotor drones that do not require precise airspeed measurements (Brown, 2018).

These sensor combinations have significant limitations, particularly in obstacle detection. Inertial and magnetometer sensors cannot detect objects around the UAV, increasing the risk of collision without dedicated obstacle avoidance sensors. Furthermore, the sensors' sensitivity to environmental disturbances

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such as electromagnetic fields and weather changes can impair the performance of the autopilot system (Pratiwi & Sahal, 2024). Therefore, these systems focus more on stability and basic navigation, rather than on real-time automatic obstacle avoidance capabilities. The addition of optical sensors is an innovative solution to address these shortcomings by providing real-time obstacle detection capabilities, improving the safety and efficiency of UAV flights (Anderson & Kumar, 2022).

However, while this technology has proven effective in mission mapping, monitoring, and dispatching, current autopilot systems still have a number of significant limitations, particularly when UAV are operated in unstructured or complex environments. Reliance on GPS signals is one major drawback. In areas with weak signal protection, such as under dense forest canopy, narrow corridors between tall buildings, or indoors, the navigation system can become unstable or even fail completely. Furthermore, conventional autopilot systems generally lack active obstacle detection and avoidance capabilities, making them vulnerable to collisions with unexpected objects such as power lines, trees, buildings, or other UAV. This has led to the development of optical sensor-based autopilot systems for real-time obstacle detection on UAV.

2 Research Met hodology

a. Formulation of the problem

- How to design an optical sensor-based autopilot system that is capable of detecting obstacles in real-time on a UAV?
- How effective are optical sensors in detecting and avoiding obstacles in dense or unstructured environments?

b. Research purposes

- Developing an optical sensor-based autopilot system capable of detecting obstacles in real-time.
- Analyzing the effectiveness of obstacle detection with optical sensors on UAV in various environmental conditions.

c. Research methods

The method used in this research is a literature review with a qualitative approach. The purpose of this study is to examine and analyze various previous research findings relevant to the topic of optical sensor-based autopilot system innovation. The sources used include reputable national and international journals covering optical sensors, UAV development, RGB, and LiDAR.

The selected literature must be directly related to the research topic and published in Indonesian and English between 2015 and 2025. The collected data will be analyzed qualitatively by comparing and synthesizing the contents of the literature, to find general patterns, important findings, strengths, weaknesses, andcurrent Autopilot/UAV development.

Based on Figure 1, the research flow can be seen starting from the selection of the camera used, namely the RGB camera and LiDAR, to the final stage of mapping or camera testing in the field.

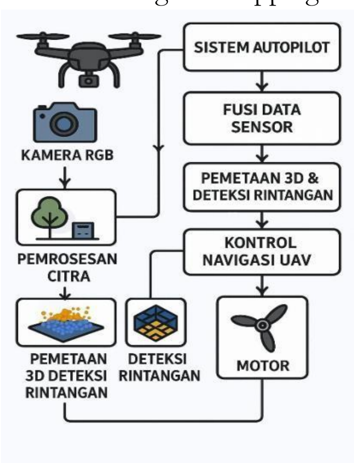

Figure 1 (Research flow)

Based on Figure 1 using RGB and LiDAR cameras because existing UAV autopilots such as accelerometers, magnetometers, barometers, and gyroscopes are still lacking in terms of safety in the field, both on highways and in rural areas full of trees. In addition, Unmanned Aerial Vehicles (UAV) which have experienced rapid development in recent years, namely the GPS system and the Initial Navigation System (INS) are still inadequate and still have shortcomings.

GPS is a satellite navigation system that uses signals from satellites orbiting the Earth to calculate a user's position. GPS works by measuring the time it takes for signals to reach a receiver from multiple satellites. By using this information from at least four satellites, the GPS system can determine three dimensions (latitude, longitude, and altitude) with very high position accuracy (Grewal et al., 2006). GPS relies heavily on clear skies and stable satellite signals (Shang & Shen, 2019).

Furthermore, INSs that rely on inertial sensors such as accelerometers and gyroscopes are capable of measuring the UAV' motion and orientation internally, but these sensors are susceptible to accumulated error (drift) over time without external correction. This leads to a decrease in the UAV's position and orientation accuracy when used alone without the support of GPS or other correction systems (Smith, 2020). While the combination of GPS and INS is commonly used to improve navigation accuracy, neither system offers direct obstacle detection capabilities. These systems rely solely on position and orientation data, leaving the UAV vulnerable to collisions with unexpected objects in complex and dynamic flight environments (Debnath et al., 2024).

Figure 2 (Auto Pilot System Design)

Figure 2 is a design of an optical sensor-based autopilot system. One technology that has emerged as a sophisticated solution is an optical sensor-based autopilot system such as an RGB camera, combined with LiDAR (Light Detection and Ranging).

3 Results and Discussion

The test results were obtained from a literature study conducted to assess the performance of an optical sensor-based autopilot system in detecting and avoiding obstacles in real-time. RGB cameras are used to identify objects based on color, shape, and contour, while LiDAR measures object distances with high precision. Combining data from both sensors through a sensor fusion process improves overall detection accuracy. The system uses a combination of RGB cameras and LiDAR sensors mounted on an autonomous vehicle, tested in a semi-controlled environment with various types of static and dynamic obstacles such as traffic cones, artificial pedestrians, and randomly moving vehicles.

Based on the literature study, the results of the comparison between RGB cameras and LiDAR were obtained so that they are suitable for use as optical sensors on autopilots, as can be seen in Table 1.

Testing Aspects	RGB Camera	LiDAR	Fusion
Main function	Visual detection:	3D distance and	Improved detection

	color, shape, contour	shape measurement	& navigation accuracy
Static obstacles (detection accuracy)	90%	94%	96%
Dynamic obstacles (detection accuracy)	85%	89%	91%
Response time detection	±1.2 seconds	±1.0 seconds	±0.8 seconds
Low light conditions	Performance decline (difficult to classify)	Stay stable	Compensatedwell by LiDAR
Weather conditions bad	Decrease	Stable	Fixed combination accurate
Small objects/mater ials opaque	Generally detected	Hard to detect	Performance increases thanks to detection additional visuals
Deviation from the path ideal	±25 cm	±20 cm	±15 cm

Table 1. shows that the RGB camera and LiDAR (Xie et al., 2021).

Table 1 shows that the RGB camera and LiDAR are very effective as an autopilot system, as they can operate well in areas filled with trees and other obstacles. Based on the comparison table of test aspects between the RGB camera, LiDAR, and the combined system, it can be concluded that the combined system provides the best overall performance in UAV detection and navigation.

While the use of GPS and INS systems in UAV autopilots is crucial for navigation and flight stability, both have safety limitations, particularly in real-time obstacle detection and avoidance. GPS relies heavily on satellite signals, which can be disrupted or lost in areas with dense canopy, tall buildings, or enclosed spaces, leading to positional inaccuracies and potential navigation failures (Fauza, 2025). While INS can measure the UAV's internal motion, it is prone to drift over time without external correction, resulting in decreased positional accuracy when used alone. Furthermore, both systems cannot detect objects or obstacles around the UAV, so the risk of collision remains high without additional sensors.

Thus, the integration of cameras and LiDAR significantly mitigates the respective limitations of GPS and INS. With the help of the SLAM (Simultaneous Localization and Mapping) algorithm, the vehicle is able to map its environment and maintain its path with an average deviation of less than 15 cm from the ideal path. Overall, the system performs well in real-time obstacle detection and avoidance.

LiDAR, and combined system (fusion), it can be concluded that the combined system provides the best overall performance in UAV detection and navigation. The main function of the combined system that integrates visual detection from RGB cameras and 3D distance measurement from LiDAR is able to improve the accuracy of obstacle detection both static (96%) and dynamic (91%) compared to the use of RGB cameras (9 Overall, the innovation of the combined optical sensor and LiDAR system provides the best solution to improve accuracy, response speed, and resilience to challenging environmental conditions in obstacle detection and UAV navigation. 0% and 85%) or LiDAR alone (94% and 89%).

By using an RGB camera that functions to capture images of the environment around the vehicle, which can be used to detect objects, roads, and other visual features. One of the main applications of RGB cameras in autopilot systems is Visual Odometry (VO) and Simultaneous Localization and Mapping (SL and Simultaneous Localization and Mapping (SLAM). Visual Odometry (VO) is a part of the RGB Camera that can be used to measure vehicle movement based on changes in images received over time. By analyzing the differences between successive images, the system can describe changes and orientation of the vehicle, which is very important when GPS position data or INS position data are not available or less accurate (Nistér et al., 2004).

On the other hand, Lidar uses laser beams to measure the distance to objects with great precision. This technology produces a three-dimensional map of the surrounding environment, providing more detailed data on the position and distance of objects (Zhang & Singh, 2017). The advantage of Lidar lies in its ability to function well in various lighting conditions, both during the day and at night, and in inclement weather due to its A*.

A* is a shortest path finding algorithm that considers obstacles and goals. This algorithm uses two cost functions: g(n), which is the distance from the starting point to the current point, and h(n), which is the estimated distance from the current point to the goal (Hart et al., 1968). Besides A*, another method often used for obstacle avoidance is the Potential Field Method. In this method, the drone is calculated with an attractive force that pulls it to the goal and a repulsive force that avoids the drone from detected obstacles. The total force resulting from the combination of these two forces is used to direct the drone's movement (Khatib, 1986).

Overall, image processing and obstacle avoidance algorithms based on RGB cameras and LiDAR enable drones to fly autonomously by avoiding objects and obstacles in their path. This system is very useful in various applications, including aerial mapping, infrastructure inspection, and search and rescue (Colomina & Molina, 2014). With the ability to combine visual and depth data, drones can make smarter and safer flight decisions in complex and dynamic environments (Oleynikova et al., 2016).

This can be explained by the equation for the RGB lens, namely

$$1/f = 1/u + 1/v \qquad \text{......................... (1)}$$

f = focal length of the lens uuu = distance of the object to the lens
vvv = distance of image from lens

For the Lidar lens equation is

$$D = CT / 2 \qquad \text{............................... (2)}$$

d = distance to object
ccc = speed of light in a vacuum
ttt = light travel time from transmitter to object and back

Thus, the integration of optical cameras and Lidar enables vehicles to obtain a more complete and accurate picture of their surroundings. Cameras capture richer visual details, while Lidar provides highly precise topographic and depth information (Geiger et al., 2012). With data from these two sensors, autopilot systems can make smarter decisions in planning routes, avoiding collisions, and interacting with dynamic objects such as pedestrians or other vehicles on the road (Cadena et al., 2016).

With the integration of LiDAR and RGB cameras, UAV can perform real-time obstacle detection with higher accuracy and greater resilience to challenging environmental conditions. This is crucial for improving flight safety, reducing the risk of collisions, and enabling more reliable autonomous operations in applications such as mapping, monitoring, and inspection (Ariska & Syawal, 2025). Therefore, the combined use of LiDAR and RGB cameras represents a superior technological innovation compared to relying solely on GPS and INS in UAV autopilot systems.

4 Conclusion

Unmanned Aerial Vehicles (UAV) play a vital role in various sectors and continue to evolve with technological advancements. Current UAV autopilot systems rely on sensors such as accelerometers, gyroscopes, magnetometers, barometers, GPS, and Inertial Navigation Systems (INS) for navigation and flight stability. However, these sensors have limitations, particularly in real-time obstacle detection and in complex environmental conditions such as areas with weak GPS signals or confined spaces. The reliance on GPS signals and the lack of active obstacle avoidance capabilities make UAV vulnerable to collisions with unexpected objects.

For further development, it is recommended to add an infrared camera and optimize the machine learning algorithm to improve the system's adaptability to low-light conditions and complex dynamic objects. An optical sensor-based autopilot system that combines an RGB camera and a LiDAR sensor has successfully demonstrated effective performance in detecting and avoiding obstacles in real time. Field testing has proven the integration of both sensors through data fusion and algorithms. Therefore, the innovation of an optical sensor-based autopilot system is an important solution to improve real-time obstacle detection capabilities. Optical sensors can complement the limitations of conventional sensors by providing accurate and fast visual data, enabling UAV to avoid obstacles automatically and improve their operational safety and efficiency. The integration of optical sensors in UAV autopilot systems is a crucial step forward to meet the challenges of increasingly complex and dynamic flight environments in the future.

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