Comparative Analysis of Ultrasonic, Infrared, and LIDAR Sensors for Obstacle Detection in Urban Drones

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Abstract

In increasingly urbanized environments, safe navigation of drones is essential for their broader adoption in consumer and commercial applications. This study evaluates the obstacle detection accuracy of three frequently used distance sensors – Light Detection and Ranging (LIDAR), ultrasonic, and infrared – when mounted to a student assembled drone flown in a simulated urban environment. The drone was piloted towards a flat wall, and sensor readings were recorded and evaluated against actual distances obtained via a laser tape measure. Each sensor underwent four trials: two when the drone was actively hovering above the ground, and two when the drone was off and grounded. Results showed that errors in readings were particularly low during elevated trials for the LIDAR and the ultrasonic sensor. The ultrasonic sensor exhibited a greater degree of error when grounded. In contrast, the infrared sensor was highly limited by its range and environmental conditions, producing inconsistent readings and high variability. These findings highlight the strengths and weaknesses of each sensor. The data suggests that LIDAR is the most reliable sensor for single-sensor obstacle detection.

Designing drones capable of accurate obstacle detection is a challenging yet essential task; it can make the difference between utter chaos and safe flight paths, especially in urban environments. Finding ways to make drones safer and more accurate is vital to developing the technology for more widespread consumer applications. How do the individual detection capabilities of ultrasonic, infrared, and LIDAR sensors compare in urban environments, and at what respective distances do they begin to accurately sense obstacles when mounted on a student-designed drone? To address this question, a distance-sensing drone was constructed. To simulate an urban environment, the drone was flown toward a flat wall until the onboard sensors started to read distance values. The sensor distance measurements were compared to the distances obtained using a laser digital measuring tape.

Literature Review

Drones are a type of Unmanned Aerial Vehicle (UAV) used for a variety of technical applications. Drones have proven to be applicable in medical supply delivery, disaster response and relief assessment, surveillance and reconnaissance, and even in agriculture using crop monitoring and health assessment (Emimi et al., 2023). Drone technology has yet to be utilized for consumer purposes, despite its persistent use in other fields. People living in urban areas cite safety and risk issues as reasons not to adopt drones in cities (Zhang et al., 2022).

In urban environments, drones can be utilized for large-scale city mapping, urban modeling, and urban planning (Noor 2018). Drones must, however, navigate the dense and dynamic environments of cities, such as tall buildings, narrow streets, and potentially other UAVs sharing the airspace. Drone adaptability, especially in terms of sensor capabilities, must also be able to respond to and avoid incidents such as obstacle collisions.

Historically, drones capable of remote sensing have used either ultrasonic sensors, infrared sensors, or LIDAR. Ultrasonic sensors emit high-frequency sound waves that bounce off objects and return to the sensor. These sensors are able to determine velocity by measuring the difference in the time it takes for sound to pass through a transducer, a device that senses when the sound wave hits the receiver. (Davies et al., 2018). Infrared sensors are commonly utilized as Time-of-Flight sensors (ToF). They emit a ray of infrared light and record the amount of time it takes to come back. Infrared sensors are utilized in agriculture drones to determine the reflectance of vegetation to determine chlorophyll concentration for a field of plants (Louw et al., 2024). Finally, LIDAR emits several laser pulses, which are then reflected and returned to the sensor to create a 3D map of an environment. Drones equipped with LIDAR are used to create detailed topographies of large landscapes and forest structures (Kellner et al., 2019).

Sensors for obstacle detection each carry their challenges. Ultrasonic sensors are capable of short-range distance measurements and are commonly used for landing assistance. While they are generally effective, these sensors can have problems detecting distances when it relates to drone noise and related measurement errors (Kazan & Solak, 2023). Infrared sensors perform well in low-light conditions, but their accuracy is hindered by reflective or transparent surfaces like glass on buildings (Mohammad, 2009). LIDAR is precise and able to detect far-away obstacles, but it is highly sensitive to weather conditions, such as smog or rain, which can distort readings (Ramasamy et al., 2016).

Fully utilizing distance sensors for different applications is an ongoing optimization problem. The goal of this research is to evaluate the accuracy of each sensor when mounted onto a student-designed drone flying in an urban environment. By comparing sensor data to distances measured from the ground in a simulated urban environment, this study aims to identify the most effective sensors or sensor combinations for reliable obstacle-distance detection in an urban setting.

Methodology

A drone kit fitted with 2210 brushless motors and 9450 propellers were used to collect data needed to address the research question. This drone kit was selected as an affordable solution for urban navigation and better represents the general drone design that would be used in such environments. The flight controller, a PixHawk 2.4.8 powered an Arduino Uno fitted with a 433 MHz Bluetooth antenna to transmit data to another Arduino Uno equipped with the same transceiver. Each motor was wired alongside an Electric Speed Controller (ESC) to control the incoming power and level the drone and was connected to a power distribution board with an 11.1-volt LiPo battery. The drone was controlled via a 2.4 GHz radio and fitted with a radio receiver that interfaces with a transmitter controller.

Each distance measurement sensor was integrated into the drone via a 3D-printed mount that extends below the drone and faces outward toward the front. An HC-SR04 ultrasonic sensor, a VL53L0X infrared sensor, and a TF-Mini S LIDAR sensor were interchanged during testing. Transceivers were connected to the separate Arduino transmitted data via serial to a laptop and provided recorded sensor values.

The drone’s testing environment consisted of a flat concrete wall. Data was collected at midday to minimize the impact of lighting and weather conditions on its accuracy. The drone hovered approximately three feet above the ground and was manually piloted towards the wall at a controlled speed.

The data collection process began with the drone being set at a fixed distance away from the wall. This fixed distance was measured using a laser digital tape. The drone was then piloted towards the wall. During this controlled flight, the onboard sensor recorded the distance to the wall. Once the sensor recorded a value within its range, the drone was landed and the distance from the wall to the drone was measured. This process was repeated several times for each sensor to ensure the precision of sensor readings across trials. Each sensor was used for a total of four trials, two trials for when the drone was elevated, and two trials for when the drone was grounded. Grounded readings were examined to investigate the potential effect the drone had on the readings of the sensor's distance measurements. Once all trials were completed, the difference between sensor readings and the controlled measurements were calculated to determine the most accurate sensor.

Results

This study’s results are presented as graphs consistent with the methodology introduced in the previous section. Figure 1 shows a comparison of the sensor performance with respect to true ground measurements, while Figure 2 provides a measurement comparison for the trials performed at ground and elevated levels.

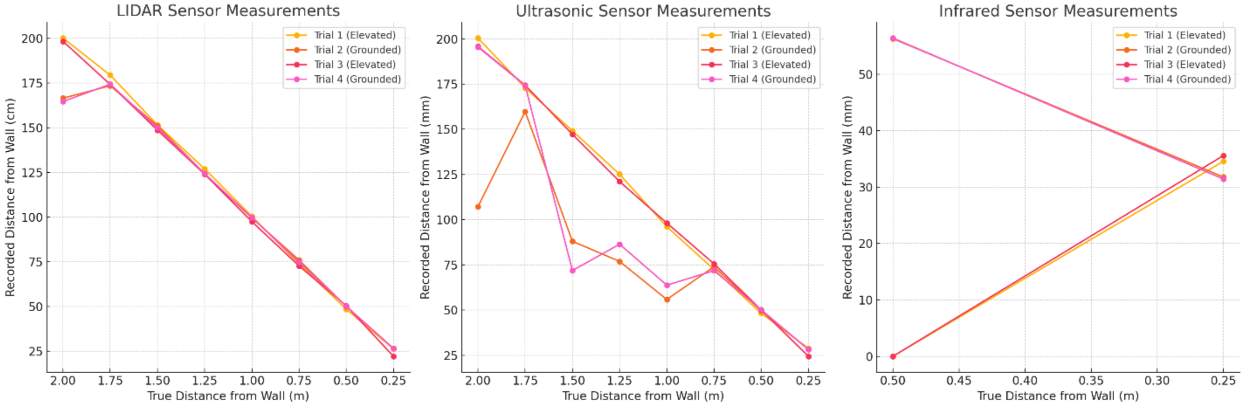

Fig 1. Sensor Performance Comparison as they relate to true ground measurements. Figure displays the distance readings recorded by LIDAR, ultrasonic, and infrared sensors at various actual distances (0.25 m – 2m) under both elevated and grounded drone positions. Each sub plot corresponds to different sensor types. The LIDAR sensor shows linear and consistent readings across all trials. The ultrasonic sensor exhibits greater variability, especially at midrange positions when grounded. Infrared shows non-linear and inconsistent behavior and only collected distance readings at distances <0.5 m.

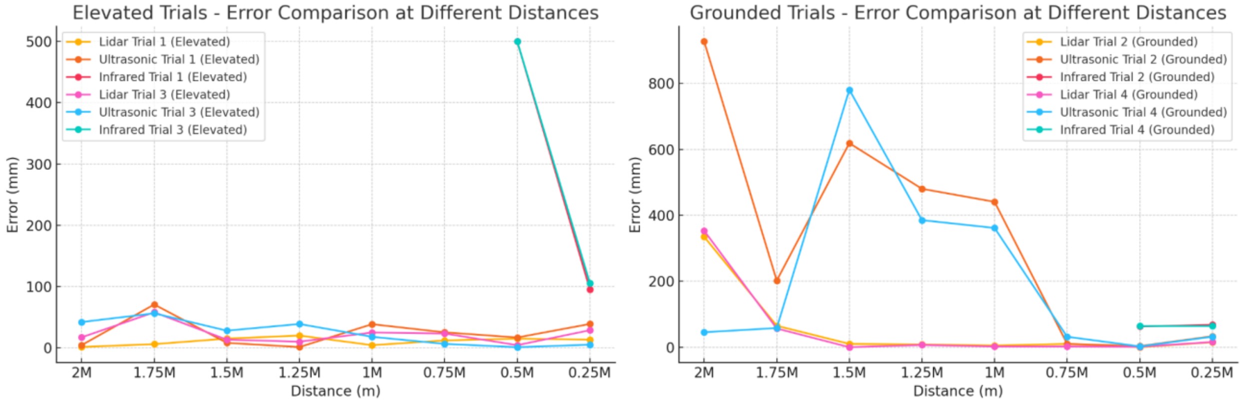

Fig 2**.** Measurement Comparison for Elevated and Grounded Sensor Trials. Figure shows average error at fixed distances across all trials for LIDAR, ultrasonic, and infrared sensors, with two subplots. On the left is the elevated error comparison, on the right is the grounded error comparison. The LIDAR sensor maintained minimal error under both configurations. The ultrasonic sensor produced higher error values in grounded trials, particularly in the mid-range. The infrared showed a larger error at the shortest distance in the elevated trials, but a noticeable decline in the error when the drone was grounded.

The analysis of the data collected indicates that LIDAR performed consistently well in terms of accuracy. While elevated, the error remained low across all distances measured, with the error remaining under 50 mm and averaging at 15.9 mm. At shorter distances, the error decreased to its lowest. LIDAR, when grounded, showed a significant increase in the error of measurement, reaching a maximum error of 344 mm at 2m, and an average error of 49.1mm. A significant drop in error was observed as the drone was moved closer to the wall used for testing purposes and significantly leveled out to near-perfect readings at 1.5 m. The Ultrasonic sensor at an elevated position remained relatively consistent in its readings, reaching a maximum average error of 80mm at a distance of 1.75m away, with an average error of 18.73mm. When grounded, the Ultrasonic sensor revealed particularly higher errors generating around the 1.5m mark up to the 1-m mark, with the highest average error recorded at 1.5m to be nearly 699 mm. The Ultrasonic sensor, when grounded, had an average error of 269.60mm. The Infrared Sensor performed the poorest, with high variability and an inability for the sensor to record distances. The Infrared Sensor in an elevated position had an effective range of 0.25m, but with an average 100mm error. The Infrared Sensor, when grounded, improved its overall range, allowing for readings at 0.5m and a relatively lower error compared to its elevated position, with an average error of 64.73mm.

Discussion

In this study, the LIDAR sensor consistently outperformed the other sensors, especially during the active hovering of the drone. This sensor was experimentally determined to have a large 11.34-m effective range, which gives it the capability to sense objects much farther away in its environment. However, the increase in the error at grounded intervals suggests that some physical interference from the surrounding environment affected the sensor accuracy. This may be attributed to higher temperatures near the ground, and the presence of suspended dust particles, both of which have been known to interfere with LIDAR performance (Ramasamy et al., 2016).

The Ultrasonic sensor, while less accurate than the LIDAR, provided relatively stable measurements across distances while elevated. While testing, the effective range of the sensor was determined experimentally to be 4.0 m

Finally, the Infrared sensor showed significant variation in performance, possibly due to the potential bright lighting of the environment and the drone's slight movement. The observed range of the Infrared sensor equipped on the drone was significantly smaller than the advertised 1.2 m value. The reflective surface in the test environment may have contributed to the variability of the sensor's distance measurement, which is well-studied and confirms prior research as suggested by Mohammad (2009).

Conclusion

This study provides a valuable insight into the performance of three commonly used distance measuring sensors – LIDAR, Ultrasonic, and Infrared. LIDAR is the most reliable option for obstacle detection in urban environments when mounted on to a drone. It performed consistently well during elevated trials, and experienced slight variability in the grounded position. The ultrasonic provided to be effective when elevated but exhibited more significant error when grounded in the mid-range distances. The infrared sensor has the most limitations, with high variability and an inability to reliably detect obstacles at longer distances.

This research highlights the need for careful consideration when choosing sensors for urban drone navigation. While LIDAR is the best option for long-range detection, it is the costliest. Ultrasonic may serve as a reliable backup for short-range detection or integrated with a LIDAR sensor. The infrared, due to its limited range and susceptibility to environmental conditions, is the least suitable choice for obstacle detection in urban environments.

The research suggests that future work should explore the effectiveness of various sensor combinations to determine a reliable combination of sensors. Developing sensor integration strategies to combine the strengths of each sensor type could potentially improve overall obstacle detection accuracy and reliability. By addressing the limitations of each individual sensor and exploring new sensor combinations, future research can contribute to the development of safer and more reliable drones, paving the way for broader adoption in urban environments.

Works Cited

Davies, D., Bolam, R., Vagapov, Y., & Excell, P. (2018). Ultrasonic sensor for UAV flight navigation. 1-7. 10.1109/IWED.2018.8321389.

Emimi, M., Khaleel, M., & Alkrash, A. (2023). The current opportunities and challenges in drone technology. Int. J. Electr. Eng. and Sustain. https://ijees.org/index.php/ijees/article/view/47

Kazan, F. A., & Solak, H. (2023). Improvement of ultrasonic sensor-based obstacle avoidance system in drones. International Journal of Aeronautics and Astronautics, 4(1), 9–35. https://doi.org/10.55212/ijaa.1261912

Kellner, J. R., Armston, J., Birrer, M., Cushman, K. C., Duncanson, L., Eck, C., Falleger, C., Imbach, B., Král, K., Krůček, M., Trochta, J., Vrška, T., & Zgraggen, C. (2019). New Opportunities for Forest Remote Sensing through ultra-high-density drone lidar. Surveys in Geophysics, 40(4), 959–977. https://doi.org/10.1007/s10712-019-09529-9

Louw, A. S., Chen, X., & Avtar, R. (2024). Assessing the accuracy of an infrared-converted drone camera with orange-cyan-NIR filter for vegetation and environmental monitoring. Remote Sensing Applications: Society and Environment, 35, 101229. https://doi.org/10.1016/j.rsase.2024.101229

Mohammad, T. (2009). Using Ultrasonic and Infrared Sensors for Distance Measurement. World Academy of Science, Engineering and Technology, 3(3), 267 - 272.

Noor, M., Abdullah, A., & Hashim, M. (2018). Remote Sensing UAV/drones and its applications for urban areas: A Review. IOP Conference Series: Earth and Environmental Science, 169, 012003. https://doi.org/10.1088/1755-1315/169/1/012003

Ramasamy, S., Sabatini, R., Gardi, A., & Liu, J. (2016). Lidar obstacle warning and avoidance system for unmanned aerial vehicle sense-and-avoid. Aerospace Science and Technology, 55, 344–358. https://doi.org/10.1016/j.ast.2016.05.020

Zhang, Y., & Kamargianni, M. (2022). A review on the factors influencing the adoption of New Mobility Technologies and services: Autonomous Vehicle, drone, micromobility and mobility as a service. Transport Reviews, 43(3), 407–429. https://doi.org/10.1080/01441647.2022.2119297