Challenges in LiDAR-based Detection of High-Speed UAVs: Experimental Analysis

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***Abstract*—The increasing use of unmanned aerial vehicles (UAVs) across multiple domains presents significant opportunities but also raises critical security threats, including unauthorized surveillance and direct attacks. Conventional detection systems such as radar, vision, and acoustic methods face considerable limitations, especially against UAVs flying rapidly at low altitudes. LiDAR technology, offering reliable detection under adverse weather and low-light conditions, has emerged as a promising alternative. However, detecting fast-moving UAVs using LiDAR is challenging due to the sparse and indistinct point clouds generated by high-speed objects. In this study, we experimentally evaluate LiDAR point clouds from UAVs , identify key detection difficulties, and suggest directions for future research toward effective UAV surveillance solutions.**

***Index Terms*—UAV, LiDAR, Point cloud**

I. Introduction

Advancements in industry and technology have significantly expanded the use of UAVs across diverse sectors such as logistics [1], highlighting their growing importance. However, recent increases in UAV misuse pose severe threats, ranging from security breaches of military installations to direct attacks, including bombing incidents [2]. Malicious UAVs typically fly at low altitudes and high speeds, making them difficult to detect using conventional surveillance systems. Radar, a representative detection technology, struggles to identify low-altitude UAVs due to inherent installation limitations [3]. Vision-based systems suffer performance degradation under adverse weather or low-visibility conditions, such as nighttime operations [4]. Acoustic-based detection methods also lose effectiveness in noisy environments [5].

In this paper, we propose UAV detection using LiDAR technology. Despite having a relatively short detection range, LiDAR is advantageous for capturing UAVs flying at low altitudes. Moreover, as an optical technology, LiDAR performs reliably under challenging weather conditions and at night. Although recent research has begun to leverage LiDAR for UAV detection, accurately measuring high-speed UAVs presents several unresolved challenges. Therefore, this paper investigates the issues encountered when detecting high-speed UAVs using LiDAR and outlines future research directions. Section II introduces related research, Section III describes the experimental setup for field measurements, Section IV presents the experimental results, and Section V concludes the paper.

(a) Aquila UAV (b) LiDAR Sensor

Fig. 1: UAV and LiDAR used in experiments.

II. Related Work

There have been several attempts at LiDAR-based UAV detection. For instance, Park et al. [6] used sensor fusion with LiDAR and visual sensors, applying a Kalman filter for improved detection. However, this study relied heavily on simulations, limiting their applicability to real-world scenarios. Abir et al. [7] experimentally verified LiDAR detection of stationary UAVs at various distances under controlled conditions. Nevertheless, this study do not fully represent realistic UAV behavior because it used mainly stationary targets. Additionally, Ha Sier et al. [8] combined LiDAR-generated images with traditional vision techniques for real-time UAV tracking, particularly beneficial in GNSS-denied scenarios. Yet, their approach still faces challenges in poor visibility conditions such as nighttime operations.

III. Experimental setting

Fig. 1 shows the UAV and LiDAR used in our experiments. We utilized the Argosdyne Aquila 3 UAV, which measures 590 × 575 × 285 mm. And data acquisition is performed using an Ouster OS1-128 LiDAR sensor, which features 128 vertical channels. The LiDAR has a maximum detection range of 200 m at 80% reflectivity and 90 m at 10% reflectivity with a 20 Hz frame rate. We conducted measurements by configuring this UAV and LiDAR as shown in Fig. 2. For this setup, the LiDAR was mounted on a chair placed in an open field. The experiment involved capturing both a hovering UAV and a UAV flying at approximately 20 m/s, aiming to compare the differences between these two conditions.

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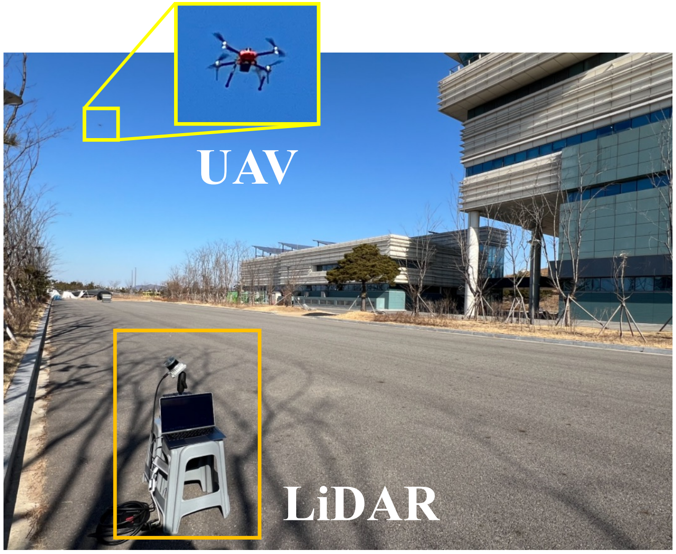


Fig. 2: UAV measurement scene using LiDAR.

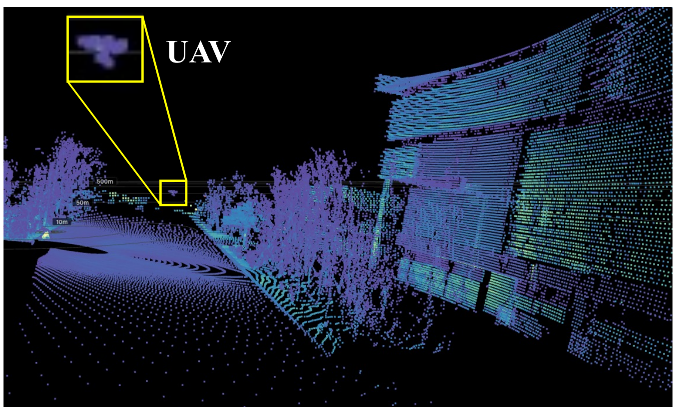
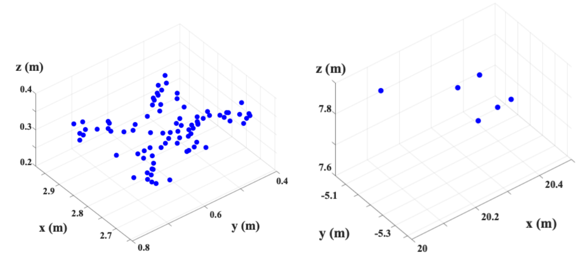


Fig. 3: LiDAR measurement results for hovering state UAV

IV. Evaluation

Fig. 3 shows an example frame from the LiDAR measurement results of a hovering UAV. As seen in the figure, the UAV appears relatively clearly defined. Using the same approach, LiDAR data was also obtained for a UAV flying at 20 m/s, and we extracted only the point cloud corresponding to the UAV for comparison. At this time, the point cloud corresponding to the UAV was extracted using a manual ROI. The results are shown in Fig. 4. Fig. 4 compares LiDAR point clouds for a hovering UAV (Fig. 4a) and a UAV flying at 20 m/s, Fig. 4b). While the hovering UAV produces a dense and clearly recognizable shape (104 points/frame), the fast-moving UAV results in an extremely sparse point cloud (6 points/frame), making shape recognition nearly impossible. This severe sparsity complicates reliable UAV detection. Comparing the results, we observed a significant reduction in the number of points for the high-speed flying UAV. This trend was consistently observed across approximately 200 frames.



(a) Hovering UAV points (b) Fast moving UAV points

Fig. 4: Results of hovering UAV and fast-moving UAV points.

V. Conclusion

Through this study, where we measured high-speed UAVs using actual LiDAR equipment, we confirmed that the number of points dramatically decreases for UAVs flying at high speeds, making it challenging to maintain their actual shape and thus difficult to detect. Additionally, it can easily be inferred that detection becomes even more challenging when such sparse points blend into complex backgrounds. Therefore, we emphasize the necessity for future research to develop rapid yet sophisticated algorithms or classification methods utilizing machine learning to reliably detect high-speed UAVs within complicated backgrounds.

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