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DESIGN AND DEVELOPMENT OF LiDAR INTEGRATED DRONE

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ABSTRACT

This research is focused on the design and development of a cutting-edge drone equipped with a cutting-edge RPLiDAR A1M8-R6 sensor. The drone's unique characteristic is its six-propeller layout, which sets it apart from regular drones. The major goal of this project is to use advanced sensor technology to revolutionize aerial mapping and surveillance capabilities. This novel approach intends to alleviate standard drone limitations, particularly in terms of obstacle recognition and mapping accuracy. We anticipate that by using the RPLiDAR A1M8-R6 sensor with a six-propeller arrangement, the drone's navigation and mapping capabilities will be considerably improved. The suggested system includes a custom-built drone that has been precisely manufactured to be lightweight and agile, allowing for improved flying efficiency and maneuverability. The integration of the RPLiDAR A1M8-R6 sensor, known for its outstanding lidar capabilities, is critical to this system. With a 360-degree scan capability and a range of up to 12 meters, this sensor gives highly accurate distance readings and enables efficient obstacle identification. As a result, the integrated drone can easily navigate complex areas while avoiding collisions. The experimental results unambiguously show that the integrated drone outfitted with the RPLiDAR A1M8-R6 sensor, and six propellers outperforms conventional drones in terms of obstacle avoidance, mapping accuracy, and overall flight performance.

Keywords: Aerial mapping, Drone, Six-propeller layout, RPLiDAR A1M8-R6 sensor.

1. INTRODUCTION

In the last decade, Unmanned Aerial Vehicles (UAVs) have achieved significant advances in scientific research as well as in real-world applications. Especially, rotary-wing UAVs have been employed for a wide range of application areas due to their vertical take-off and landing capability. Nowadays, various types of UAVs with different structures keep emerging. For instance, UAVs with six or more rotors have attracted attention due to their higher payload capacity [1–3]. Furthermore, various sensors have been mounted on the UAVs for applications such as autonomous formation flight, surveillance, target tracking, reconnaissance, disaster assistance, etc. Light Detection And Ranging (LiDAR) is one type of active remote sensing and has been widely employed as a primary ranging device in many autonomous robotic vehicles including UAVs [4–6].

Remote sensing technologies like aerial and satellite imagery are generally referred to as passive technologies because they measure how radiation from an external source (i.e., sunlight) reflects off an object. Aerial and satellite images are widely used in the natural sciences, and have been so since the launch of Landsat 1 in the 1970´s. The applications of satellite and aerial imagery are extensive, and not covered in this guide. Whereas satellite and aerial imaging are considered passive, techniques like LiDAR and RADAR are considered active, as they are not dependent on sunlight but rather emit radiation of their own and then measure how this radiation reflects from a target. RADAR is an acronym for Radio Detection and Ranging, and it is a method based on emitting radio waves and then measuring their reflection.

Similarly, LiDAR is an acronym for Light Detection and Ranging. Instead of emitting radio waves, LiDAR devices use light to detect and range. Before describing the method in greater detail, the terminology of the technique must be briefly explained. When learning about LiDAR, one is likely to encounter terms like airborne or terrestrial LiDAR, or aerial or terrestrial laser scanning (ALS or TLS). Both ALS and TLS employ LiDAR. A LiDAR device itself can be mounted on an airplane, helicopter, drone, ATV, car, or tripod. In the typical case, the LiDAR device is mounted on board an airplane and the system scan the ground from the air with a laser – hence the term airborne laser scanning. There is also a LiDAR dataset that is being collected from a device on board a satellite: GLAS (Geoscience Laser Altimetry System). This guide, however, will focus solely on ALS, because this is currently the most common method that governments and institutions use to collect their data, and the most commonly available data. Henceforth, the term LiDAR is used to refer to both the method and the data produced by the method. LiDAR mapping are an accepted method of generating precise and directly georeferenced spatial information about the shape and surface characteristics of the Earth. Recent advancements in lidar mapping systems and their enabling technologies allow scientists and mapping professionals to examine natural and built environments across a wide range of scales with greater accuracy, precision, and flexibility than ever before.

Several national reports issued over the past five years highlight the value and critical need of lidar data. The National Enhanced Elevation Assessment (NEEA) surveyed over 200 federal, state, local, tribal, and nongovernmental organizations to better understand how they use enhanced elevation data, such as lidar data. The over 400 resulting functional activities were grouped into 27 predefined business uses for summary and benefit-cost analysis (NDEP, 2012). Several of these activities will be described in more detail in the applications section of this document. There are many considerations and trade-offs that must be understood in order to make sound decisions about the procurement, processing, and application of lidar data. This document provides introductory and overview information, as well as in-depth technical information, to support decision-making in all phases of lidar projects. While the information presented here is not comprehensive, it covers aspects of the technology that are the most common subjects of discussion within the coastal management community. The acronym LiDAR first appeared in the literature in the 1960s and LiDAR's first application in forestry occurred in the 1970s. The widespread adoption of LiDAR for modelling forest structure began in the late 1990s, resulting in LiDAR assisted forest inventories.

2. LITERATURE SURVEY

Wallace et al. [7] presented a UAV-borne LiDAR system to collect measurements for forest inventory applications. A Sigma Point Kalman Smoother (SPKS) was applied to combine observations from different sensors. Then, Wallace et al. [8] developed a tree detection algorithm using high-density LiDAR data. The effect of point density on the accuracy of tree detection and delineation was evaluated. On the other hand, Chen et al. [9] integrated LiDAR and UAV to extract detailed surface geologic information. The random sample consensus method was adopted to ascertain the best-fit plane of bedding. Hening et al. [10] presented a data fusion technique for the position and velocity estimation of UAVs. Local position information was provided by a LiDAR sensor, and an adaptive Kalman filter was applied for the integration. Zheng et al. [11] built an obstacle detection system using LiDAR with the consideration of a moving point cloud.

To fully take advantage of UAVs in the real world, a high degree of flight safety related to a close encounter with another UAV should be guaranteed. In a real situation, the obstacle information is unknown prior to deployment, and it should be detected by a sensor mounted on the UAV during the mission. The UAV must be capable of avoiding the detected obstacle using the online-collected information. In other words, obstacle detection and avoidance are one of the most important capabilities for the success of UAV applications. Therefore, it is crucial to develop a collision avoidance strategy for the UAV to perform a given mission in a dynamic environment.

Collision avoidance against a moving obstacle has been investigated by various researchers. In the robotics field, Cherubini et al. [12] designed a set of paths during navigation to take into account the obstacle velocity, which was estimated by a Kalman filter. The estimated velocity was used to predict the obstacle's position within a tentacle-based approach. Ji et al. [13] presented a path planning and tracking framework for autonomous vehicles. The tracking task was formulated as a multi-constrained model predictive control problem, and the front wheel steering angle was calculated to prevent the vehicle from colliding with a moving obstacle. Malone et al. [14] proposed a scheme to incorporate the effect of likely obstacle motion into the desired path of a robot. The method combined an artificial potential field with stochastic reachable set for online path planning. Li et al. [15] developed a controller based on a nonlinear model predictive control for obstacle avoidance. A moving trend function was constructed to predict dynamic obstacle position variances in the prediction horizon. Zhang et al. [16] focused on the tracking of an object in the presence of multiple dynamic obstacles. A method based on conservation of energy was proposed to adjust the motion states of the robot manipulators.

On the other hand, in the aerospace field, Mujumdar and Padhi [17] developed nonlinear geometric guidance and differential geometric guidance, based on aiming point guidance. The guidance law of the UAV was made applicable for moving obstacles by incorporating the Point of Closest Approach (PCA). Wang and Xin [18] addressed the formation control problem where other UAVs are treated as moving obstacles. A nonquadratic avoidance cost function was constructed by an inverse optimal control approach so that the optimal control law was obtained in an analytical form. Yang et al. [19] designed a switching controller to achieve a spatial collision avoidance strategy for fixed-wing UAV. The UAV maintained a safe distance from an intruder by keeping the desired relative bearing and elevation during a collision course.

3. PROPOSED SYSTEM

The development process entails the intricate design and fabrication of the drone frame, purposefully engineered to accommodate the six propellers and ensure optimal stability and control. Additionally, the RPLiDAR A1M8-R6 sensor is seamlessly integrated into the drone's architecture. To facilitate

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real-time obstacle detection and mapping, the sensor data is meticulously processed and fused with the drone's sophisticated flight control system. Subsequently, the drone's control algorithms are fine-tuned and optimized to effectively utilize the sensor data for efficient flight planning and autonomous navigation. This research presents a significant contribution to the field of drone technology by introducing an innovative approach that combines sensor integration and advanced propulsion system design. The integrated drone holds tremendous potential for a wide range of applications, including aerial mapping, surveillance operations, search and rescue missions, and environmental monitoring. The findings of this study pave the way for further advancements in drone technology and highlight the critical role of sensor integration in achieving heightened performance and expanded functionality.

3.1 UAV system

Dynamics

A hexacopter is configured with six rotors, where three rotors rotate in clockwise direction and the others rotate in counterclockwise direction. A platform of the hexacopter is shown in Figure 4.1 as an example. A North-East-Down (NED) coordinate system is considered in an inertial frame. Note that flat-Earth and rigid body are assumed in this study. A body-fixed coordinate system is defined with its origin at the hexacopter center of mass and its axes (x^b, y^b, z^b) are aligned with the reference direction vector, as shown in Figure 1. The rigid hexacopter dynamics is governed by the following translational and rotational differential equations.

$$\dot{\vec{r}}^n = C_{b/n}^T \vec{v}^b$$

$$\dot{\vec{v}}^b = \frac{1}{m}\vec{F}^b + C_{b/n}\vec{g}^n - \vec{\omega}^b \times \vec{v}^b$$

$$\dot{\vec{\omega}}^b = J^{-1}(\vec{M}^b - \vec{\omega}^b \times J\vec{\omega}^b)$$

Where $\vec{r}^n \equiv [x^n \; y^n \; z^n]^T$ is the position vector of the hexacopter represented in the NED coordinate system; $\vec{v}^b \equiv [u \; v \; w]^T$ and $\vec{\omega}^b \equiv [p \; q \; r]^T$ are the velocity vector and the angular velocity of the hexacopter represented in the body-fixed coordinate system, respectively; m and $J \equiv diag[J_x, J_x, J_x]$ are the mass and inertia matrix of the hexacopter, respectively; $\vec{F}^b$ is the external force of the hexacopter represented in the body-fixed coordinate system; $\vec{M}^b$ is the external moment of the hexacopter represented in the body-fixed coordinate system; $\vec{g}^n = [0 \quad 0 \quad g]^T$ is the gravity vector represented in the NED coordinate system; and $C_{b/n}(= C_{b/n}^T)$ is the direction cosine matrix performing coordinate transformation from the NED coordinate system to the body-fixed coordinate system.

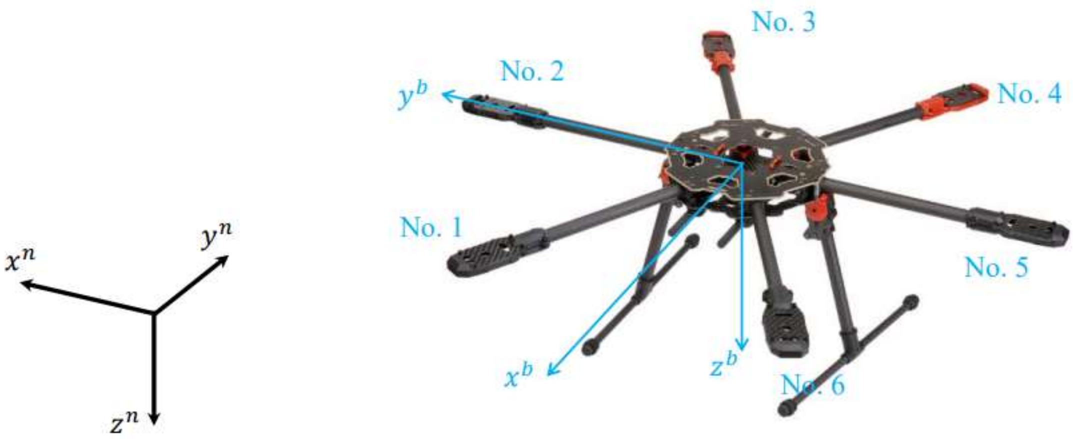

Figure 1: Hexacopter platform and its coordinate system.

Figure 2: System composition of Lidar.

Integration of LiDAR with Drone

The development of the RPLiDAR A1M8-R6 sensor integrated drone with six propellers involves combining two important components: the RPLiDAR A1M8-R6 sensor and a drone equipped with six propellers. The RPLiDAR A1M8-R6 sensor, created by Slamtec, is a compact and lightweight laser scanning solution. By emitting laser beams and measuring their reflection time, the sensor can accurately calculate distances to objects in its surroundings. It offers a scanning frequency of 8000 samples per second and has a range of up to 12 meters. The drone used in this design follows a hexacopter configuration, featuring six propellers. This design offers several advantages over traditional quadcopters, including increased stability, improved payload capacity, and redundancy. The six propellers enable more efficient distribution of lifting power, resulting in smoother flight manoeuvres and enhanced stability even in windy conditions. Additionally, the redundancy provided by the extra motors ensures that the drone can continue flying and maintaining stability if one or two motors fail. Integrating the RPLiDAR A1M8-R6 sensor with the drone allows for the collection of precise and real-time 3D mapping and environmental data. With accurate distance measurements, the drone can detect and avoid obstacles during its flight. This capability proves beneficial for applications such as autonomous navigation, obstacle avoidance, and environmental mapping.

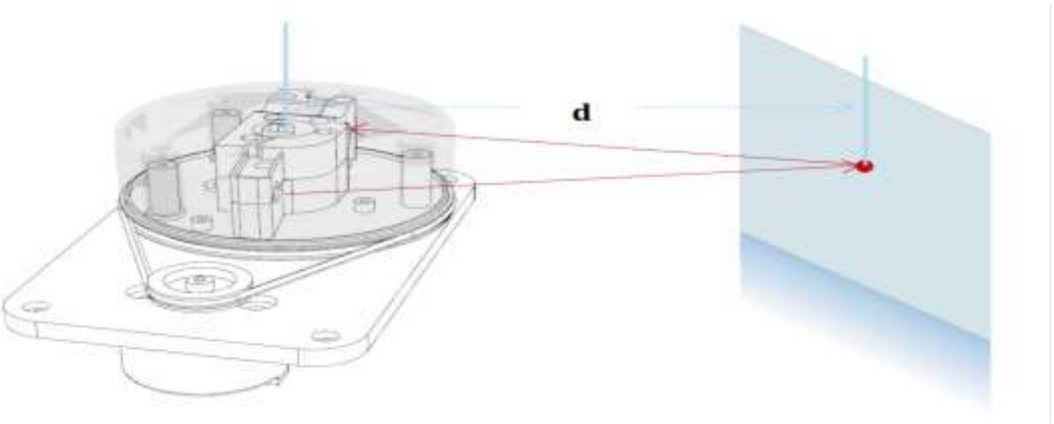

Figure 3: Working Schematic of Lidar

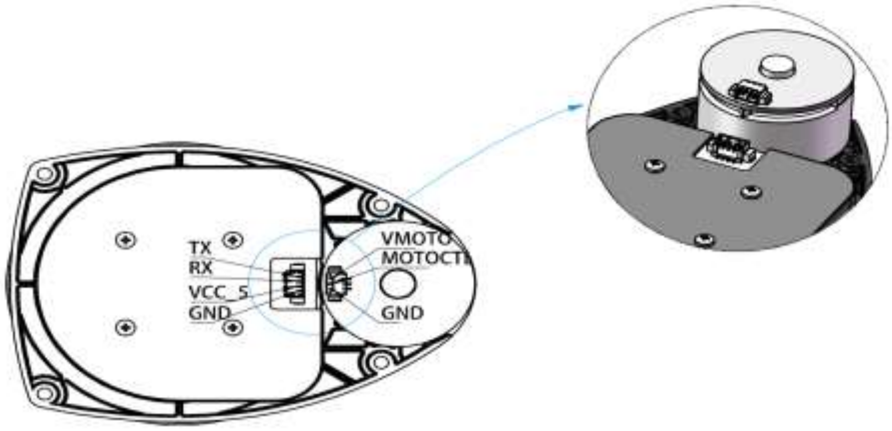

Figure 4: RPLiDAR Power Interface

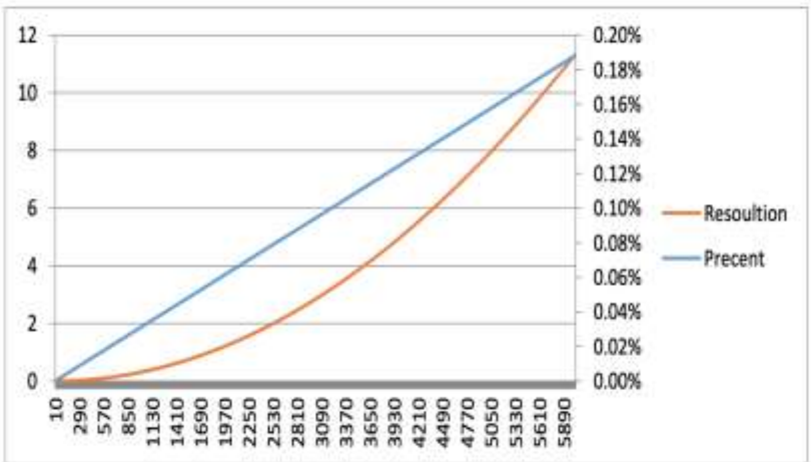

Figure 5: Resolution Graph of LiDAR.

Figure 5: LiDAR integrated Drone with six-propellers.

4. CONCLUSIONS

In this work, a collision avoidance algorithm of a hexacopter UAV is proposed. The algorithm is based on the collision cone approach and is improved to handle a moving obstacle by considering the short-term predictions for the obstacle trajectory with the aid of an obstacle state estimator. A LiDAR system on the UAV obtains the obstacle data points to form the spherical bounding box around the detected region of the obstacle and also the collision cone. Sometimes, the LiDAR system may lose the obstacle due to its limited sensing range and FoV. A collision is detected by examining the predicted position of both the UAV and the obstacle. The obstacle state estimate also contributes to an avoidance manoeuvre of UAV by removing the points that are unreasonable to be taken as candidates of the aiming point. The results demonstrate that the hexacopter properly handles the moving obstacle; unlike the previous method that does not explicitly consider the predicted relative movement. For future research, the obstacle detection and avoidance algorithm will be extended to deal with multiple obstacles. An appropriate decision-making algorithm should be developed to assess the obstacles in terms of the level of threat.

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