3D Mapping Using a UAV, an IMU, and a 2D LiDAR

Auburn REU on SMART UAVs 2019
CSSE19-04

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September 23, 2019

Abstract

The increased prevalence of unmanned aerial vehicles (UAVs) has proven advantageous for the development of useful applications for mapping interiors. Due to their small size and unmanned nature, UAVs have shown themselves to be optimal tools for indoor mapping, as they reduce risk and are highly mobile. The purpose of this research is to provide an inexpensive way for UAVs to map in any environment. Related works have created ways of accomplishing this task, using multiple LiDAR sensors or having red, green, blue, and depth (RGBD) sensors to assist their system with localization. This paper proposes a mapping method of mounting a 2D scanning LiDAR with a Pixhawk controller and yawing 360° to create an accurate, 3D representation of its surroundings in real-time. When stationary, the methods proposed can generate an accurate model of the surrounding area; however an accurate model was unattainable when the UAV moved due to localization errors. Further testing with better localization methods is required for mapping from multiple points.

1 Introduction

1.1 Background

Mapping enclosed environments has proven itself to be quite a difficult task that, on some occasions, may result in one's exposure to life threatening situations. Fortunately, with the extensive and recent development of UAV technology, it is feasible to successfully achieve such tasks, thus reducing the exposure of individuals to dangerous, enclosed environments. Moreover, unmanned aerial vehicles are often lightweight and agile, allowing for them to explore and map locations that may be unreachable for the average person.

Similarly, due to their low cost and high accuracy, 2D LiDAR have seen increased usage in UAV related applications, such as indoor mapping. Devices containing LiDAR technology work by emitting a beam of light directed at an object and then receiving the reflected light. The distances of objects are then easily and accurately computable, since both the time between emission and reception, and the speed of light are known. By using both LiDAR technology and UAVs, the goal of mapping an enclosed environment becomes a feasible task.

1.2 Related Works

A recent example of using UAVs for mapping is Ravankar *et al.*'s [3] paper on a low cost method of autonomous mapping and exploration for UAVs using a 2D LiDAR and a RGBD sensor. This method employed the 2D LiDAR and the pose estimates given by a 9 degrees of freedom (DOF) inertial measurement unit (IMU) to give a 2D occupancy grid given by the Grid Mapping (GMapping) method. Using this occupancy grid, the UAV can employ a frontier-based exploration method to navigate the full enclosed area. At the same time, the RGBD sensor is creating a 3D point cloud of the environment using the OctoMap method (an algorithm based on an octree for navigation). Studies like this one demonstrate that mounting a small UAV with lightweight, low cost sensors to obtain a 3D map of nearby surroundings and the UAV's location at the same time is quite feasible.

In addition, there is another method used for 3D mapping that was developed by Kang *et al.* [2] and also uses 2D LiDAR technology and a 9 degree of freedom (DOF) inertial measurement unit (IMU). Said method works by mounting a 2D LiDAR with a 360° field of view vertically, with its z-axis to the side, as shown in figure 1. The system then rotates the LiDAR around the vertical axis in order to create 3D point clouds. This method creates a 3D point cloud of all objects within a near-complete spherical view of the LiDAR. The stand the LiDAR was mounted onto contained a stepper motor, and as the LiDAR scanned, this motor began to rotate the stand, thus allowing the system to get the LiDAR scan data along with the current angle of the stepper motor. In addition, a second 2D LiDAR and a 9DOF IMU were used to localize the system. With this localization system, their system could create 3D maps both while moving and from known positions [2]. Though in Kang *et al.*'s [2] full system there are two LiDARs, only one of them is used to develop the 3D point cloud, giving evidence that it is feasible to create 3D maps using a 2D LiDAR and few other devices

Figure 1: The setup used by Kang *et al.* to produce 3D point clouds

Similarly, Chen *et al.* [1] developed another method that also involves mounting the 2D LiDAR vertically to create 3D maps. Along with the assistance of a Microsoft kinect, which is an RGBD sensor, Chen *et al.* [1] designed and implemented a method of making a 3D map with similar sensors used by Ravankar *et al.*'s [3]. The method uses a LiDAR mounted vertically with its z-axis pointing forward, along with a kinect sensor and an IMU to estimate the location of the system in space, as shown in figure 2. Combining all of these sensors, the system was mounted onto a TurtleBot, which was able to localize itself while making an accurate 3D map of nearby objects [1].Even though this system used similar sensors to Ravankar *et al.*'s [3] work, it switched the roles of the sensors by opting to have the LiDAR create the 3D map while the RGBD sensor localized instead. Ravankar *et al.*'s [3] work shows that these sensors can be used on a UAV, giving the possibility of doing something similar to Chen *et al.*'s [1] work by using a UAV instead of a TurtleBot.

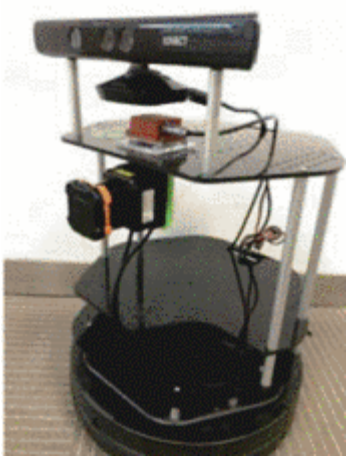

Figure 2: The setup used by Chen *et al.* to produce 3D point clouds

1.3 This Project

This paper seeks to improve upon Chen *et al.* [1] and Kang *et al.*'s [2] work by using a similar mounting style method for 3D mapping of a 2D LiDAR, a Pixhawk flight controller, and a UAV. Additionally, both of the LiDAR and Pixhawk will be connected to a Raspberry Pi 3B in order to process scan and orientation data of the sensors using ROS. Using this design, the UAV will be able to be deployed along with the RPLIDAR to begin scanning. This, will be followed by a full 360° yaw that will scan the surface of the surrounding objects. Each scan, along with the current estimates of both position and orientation, will then be sent to a remote computer which will create a 3D point cloud. This method and design were tested using an experiment that simulated flight, and found that it worked well when mapping from a single position, but problems arose when combining point clouds from multiple scans.

The rest of this paper is structured as follows: the system's design, then a description of the mapping method, then an outline of the testing phases, and finally the results of the testing.

2 Approach

2.1 System Design

The system is made of 5 primary components. **Firstly** is the RPLIDAR A1. The RPLIDAR A1 is a 360° scanning 2D LiDAR that is able to get distance data off of anything planar to it. In this case, the RPLIDAR is placed vertically in order to get the range data for all objects in this vertical plane. **Secondly** is the Pixhawk flight controller. The Pixhawk gives the linear acceleration, angular velocity and magnetic readings in 3 dimensions, it also gives the barometric pressure. Altogether, These readings are used to calculate a rough estimate of the orientation of the system. **Thirdly** is the Raspberry Pi 3B. The Raspberry Pi is used as the central computer for the system and receives the scan and orientation data from the RPLIDAR and Pixhawk, respectively. It then uses this data to create transformations necessary to create the point clouds. The **fourth** component is a remote computer. This computer is connected to the Raspberry Pi via SSH and is able to visualize the 3D point cloud using data from the Raspberry pi. It is also able to give commands to the Raspberry Pi to start and stop scanning procedures. Lastly, the **fifth** component of our system is the UAV. Its main purpose is to hold all components besides the remote computer. In a normal case, the UAV would then be able to maneuvered using its radio controller, however for the purposes of this paper the UAV will be placed on a rolling chair and will be manually moved around.

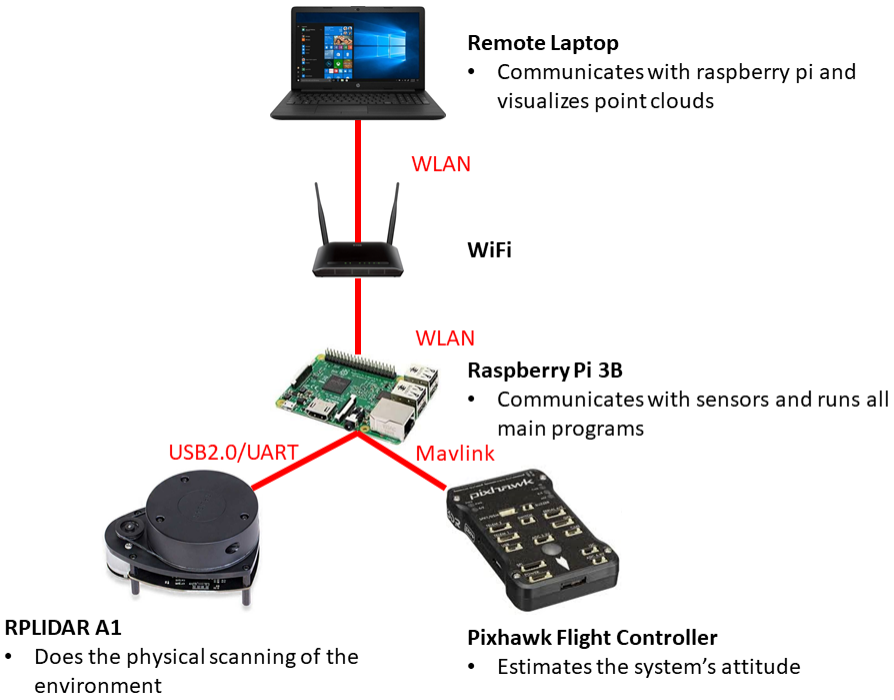

Figure 3: System setup

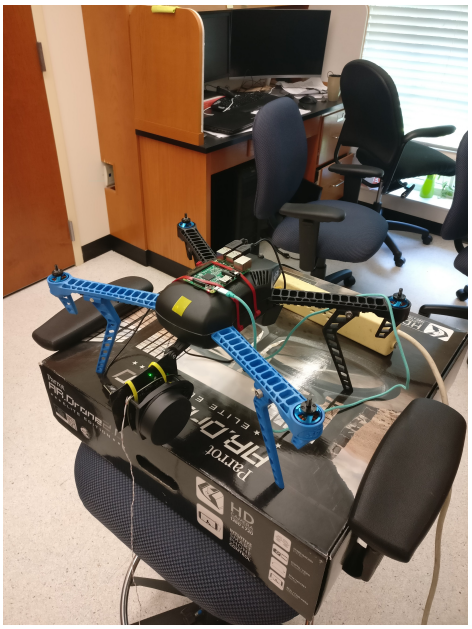

Figure 4: Physical implementation of the system

2.2 Mapping Method

The mapping method relies on the Pixhawk and the LiDAR. The LiDAR is mounted vertically onto the UAV, like in Kang *et al.*'s [2] design. This mounting style allows the LiDAR to be able to get the range data of all objects within its vertical plane. The UAV can then yaw 360° while the LiDAR scans to have this plane sweep over all of the system's environment visible from that point. This process then gives a 3D point cloud of the environment in real time that can be used as a map to guide the UAV.

As a single scan is usually not sufficient to create a map of an environment, this process can be repeated at different points, creating multiple smaller point clouds which can then be combined to form a larger point cloud that can function as a map. To do this, the system must first scan, then move, then scan again, then move, and so on for however long is necessary. This sequence of moving and scanning is slow, however each scan covers a large area, thus leading to a reduction in the number of necessary scans.

2.3 Testing

Testing this system was done in three phases of experimentation.

The **first** phase was creating a 3D point cloud using the LiDAR mounted vertically and rotating it at a known constant angular velocity. As this had already been done in past works, it was already known that this was possible, so this phase was intended to validate the findings from past studies and help get an understanding of ROS and the devices in the system.

The **second** phase was creating a 3D point cloud using the LiDAR mounted onto a UAV vertically and then rotated it at an unknown angular velocity. This phase was intended to more closely simulate the actual conditions that would arise while on the UAV, as UAVs do not always yaw at constant velocity.

The **third** phase was mounting the system onto a UAV and creating a 3D point cloud of the environment from multiple scans at different known positions. For this phase, the system was placed on a rolling chair that can rotate 360°. Using this setup, the system was manually moved from each position to another, and manually yawed to form each scan. In addition, each position was known before scanning, since the system lacks method of localization. This phase was the main goal of the project, and tested whether the proposed mapping methods can work.

3 Results

3.1 First Phase

In the **first** phase of testing, a LiDAR, in this case a RPLIDAR A2, was mounted onto a swivel mount, as show in figure 5. The LiDAR was then manually rotated at an assumed constant angular velocity of 10°/s. This method was tested twice at the same indoor environment, giving figures 6 and 7. Each scan was visualized in Rviz.

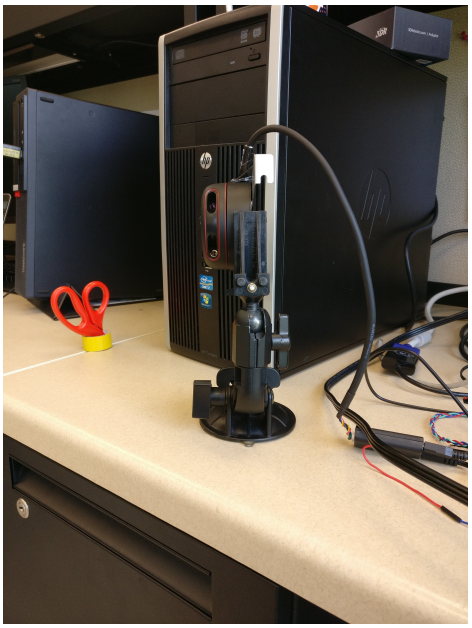

Figure 5: RPLIDAR A2 on a swivel mount. This setup was used to create the scans in phase **one**.

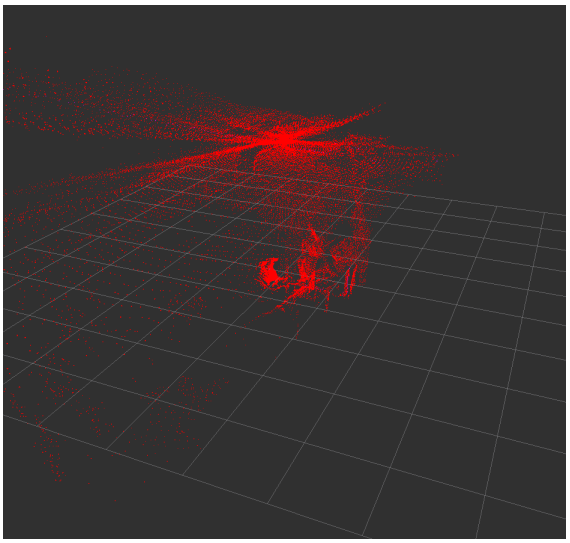

Figure 6: A 3D point cloud made assuming constant rotational velocity

Figure 6 gives a zoomed out image of the 3D point cloud made by the scan. It depicts some of the ceiling of the lab, along with 2 of the researchers and a small portion of their desk.

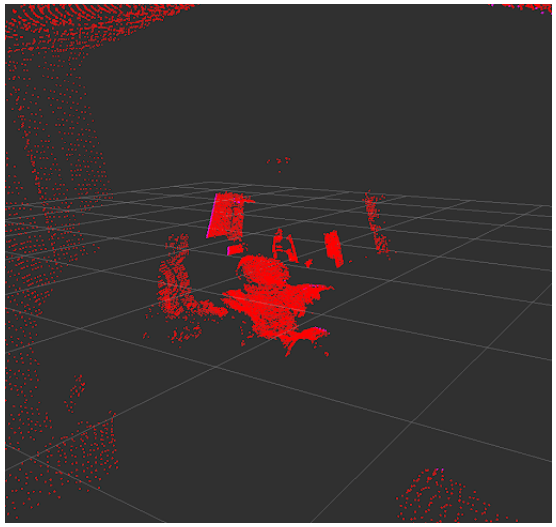

Figure 7: A 3D point cloud made assuming constant rotational velocity

Figure 7 gives a zoomed in image of another 3D point cloud made by a scan. It depicts two researchers and a small portion of their desk. One of the researchers is somewhat distorted due to them moving during a scan.

Through the point clouds made in this **first** phase, and from previous works, it was found that it is possible to make 3D point clouds using a vertically mounted LiDAR that is rotated at a constant rotational velocity. However, the scans took a considerable amount of time to make. Additionally, the scans are inexact since the LiDAR was rotated by a researcher, and it is difficult for an individual to accurately rotate the LiDAR at a constant angular velocity. This inaccuracy of rotation lead to some distortion in the images.

3.2 Second Phase

In the **second** phase, the assumption of the constant angular velocity was abandoned, and the current yaw angle of the system was given by the Pixhawk. This phase was tested by mounting the LiDAR and Raspberry Pi 3B onto a 3DR IRIS, a UAV that has a Pixhawk as its flight controller. The IRIS was then placed on a backless swivel chair, and rotated by a researcher. This method was tested twice in the same indoor location, giving figures 8 and 9. The point clouds were again visualized in Rviz.

Figure 8 shows most of the room it was created in. The walls and ceiling, along with other elements that were in the room, such as chairs, work benches, and even an overhanging power strip can be seen in this scan.

Figure 9 shows a second scan in the same room. This point cloud also has distinguishable features, such as the walls, the ceiling,an overhang, and a small portion of a workbench. Most of the features that were present in the other figure were either not present during this scan, or cannot be seen due to the viewing angle of the image.

Through the point clouds made in this **second** phase, it was found that it is possible to make 3D point clouds without assuming constant angular velocity. This is an important finding as UAVs do not yaw with constant angular velocities, so this phase gives evidence that it would be possible to create 3D point clouds using the proposed mapping method. Additionally, removing the assumption of constant angular velocity reduces the amount of distortion in the point clouds. This reduction of distortion is due to the Pixhawk's yaw estimate being more accurate than a researcher attempting to rotate the LiDAR at a constant rate. However, the scans still take a considerable amount of time to make, though this time can be reduced at the cost of the point cloud's quality. Additionally, there is also a ring at the center of both point clouds. This

ring is caused by the IRIS always being in the field of view of the LiDAR, and can easily be removed by knowing at which angles the LiDAR can scan the IRIS, and ignoring distance data from those angles.

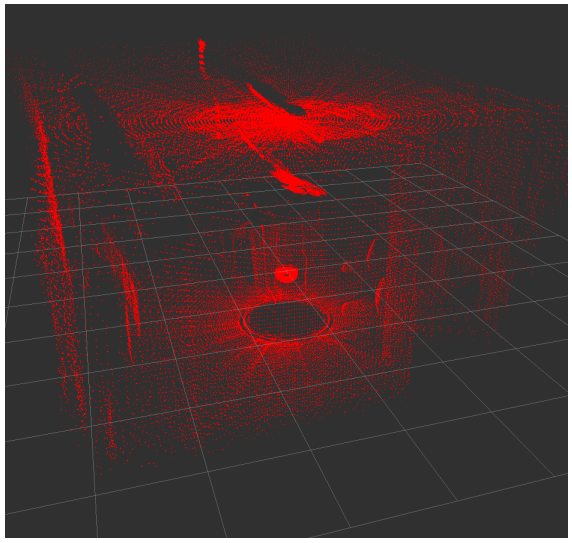

Figure 8: A 3D point cloud made using yaw angle from the Pixhawk

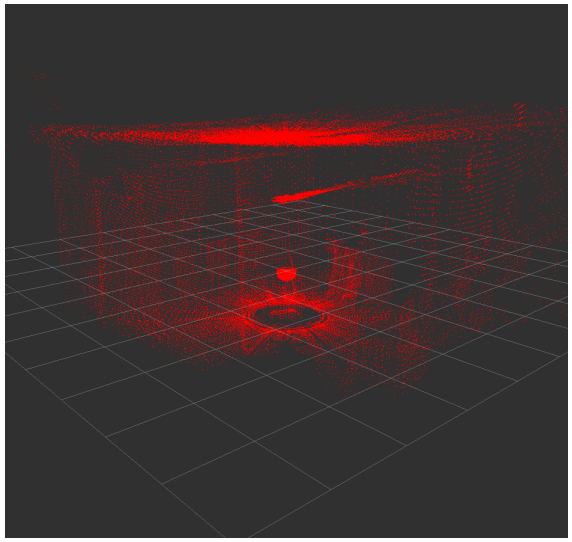

Figure 9: A 3D point cloud made using yaw angle from the Pixhawk

3.3 Third Phase

The **third** phase expands on the previous phase by repeating the mapping process at multiple known locations, and joining the point clouds together. The position of each scanning location was given to the system before the test. The system then used these known positions to piece together the point clouds using transforms from ROS. The point clouds were again visualized in Rviz.

The system took multiple scans in a hallway with a right angle, and an open area across from the turn. As shown in figure 10, this right angle was captured between the first two scans, though the opening cannot

be seen in the point cloud. However, the third scan greatly deviates from being in line with the the second scan. This deviation could have multiple causes, such as inaccuracies with the yaw calculation from the Pixhawk or yawing too quickly.

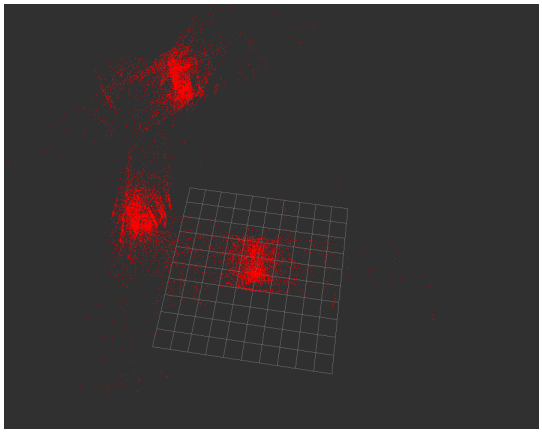

Figure 10: A 3D point cloud made from 3 different known locations

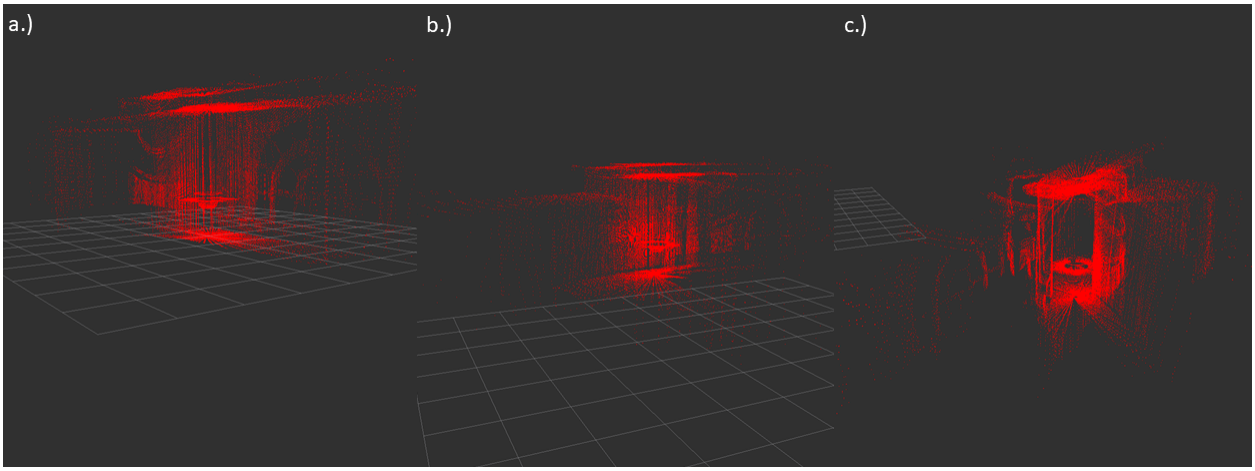

Figure 11: a.) The scan from the first location b.) The scan from the second location c.) The can from the third location

Figure 11 depicts each of the three individual scans taken during this phase. The first scan shows well defined walls, ceiling, and floor, along with outlines of the window frame in the hallway. Similarly, the second scan shows well defined walls, ceilings, and floors. There are not many other features in this scan as that area of the hallway had few features in it. The third scan is very distorted. In this scan, the ceiling, walls, and floor are not well defined. Since the distortion exists only in the third scan, and not in the first or second scans, the same two causes mentioned before are both likely to be held at fault as errors in the yaw angle increase overtime. Errors in manually yawing the system would be localized to single scans.

The rings still exists in each of the scans, as the full field of view of the RPLIDAR was still used.

4 Conclusion and Discussion

This paper proposes, implements, and studies a method of creating 3D maps using a 2D LiDAR, an IMU, and a UAV. The results from the **second** phase, and the individual scans from the **third** phase, show this method creates usable 3D maps when scanning from a single point. However, issues arose while testing from multiple points and joining together multiple scans. These issues may have been caused by errors in calibration and calculation of the yaw angle of the system, which would then make the multiple scans not line up properly. This possible cause of error is supported by the third scan in the **third** phase not aligning with the previous scans, and the second scan not being perfectly perpendicular to the first scan. This cause could be solved by using algorithms, such as the iterative closest point (ICP) algorithm, to better join scans together. These issues may also have been caused by manually yawing the system too quickly. Since it is assumed a single rotation of the LiDAR occurs at a single yaw angle, yawing too quickly would cause large amounts of distortion, and have mapped objects be at different angles than they truly are, as shown by the walls in the third scan. This cause could also be solved by using algorithms such as ICP. This cause also could be solved by yawing more slowly and better pose estimation. Due to the issues in the **third** scan, but the relative lack of issues with the first and second scans, it is inconclusive how good this mapping method is at creating maps from multiple points.

Further work is necessary to fix the complications that arose in the last phase of the project. This work includes using the remote laptop to also do ICP on each scan, so the scans can align better, and an evaluation on the quality of the maps produced by this method at various yaw rates and LiDAR scan frequencies. In addition, this system needs a form of localization, given that it cannot work without having to scan from known positions. After these works have been accomplished, this method also needs to be evaluated in real flight conditions, as UAVs are meant to be flown, instead of resting on rolling chairs.

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[2] X. Kang, S. Yin, and Y. Fen, "3d reconstruction & assessment framework based on affordable 2d lidar," September 2018.

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