Impact of Interference on Time-Of-Flight LiDAR

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Abstract

A research on the interference between Light Detection And Ranging (LiDAR) was conducted. The main objective is to assess its impact and behavior, crucial to self-driving vehicles, since LiDAR is one of the most promising sensors to augment the autonomy of vehicles, being adopted both by car manufacturers and research teams. Two conditions were studied: the distance between the LiDARs and the length of the voxel grid edges used for the statistical analysis. Our findings indicate that a smaller length of the voxel grid edges increases slightly the magnitude of the interference, for a fixed distance. Regarding the distance, no conclusion is possible, since other factors appear to be more relevant. In a worst case scenario, we conclude that one in each thousand points is expected to be interfered when two LiDARs coexist.

1 Introduction

Backed both by common sense and research, human error is still one of the causes of most accidents and injuries on the road [2, 10]. Despite increasingly road safety awareness campaigns, laws and heavier fines, annual global road traffic deaths have reached 1.35 million in 2018, being the leading cause of death for people aged 5-29 years [10].

Several studies have been conducted on self-driving technology and Advanced Driver-Assistance Systems (ADAS) [2, 3, 7], which appears as one of the most promising solutions to mitigate road accidents. Along with some public datasets that have been made available to **further the development** of self-driving vehicles [4], ADAS is becoming more relevant, mainly due to the maturation of LiDAR technology [9].

LiDAR sensors map their surroundings thanks to their capability of precisely measuring depth - with a few centimeters of error, over distances that can range until 100 meters [1, 9]. Time of Flight (TOF) LiDAR, the most common type, acquires depth information by measuring the time elapsed between the emission and reception of a laser pulse reflected from a surrounding target [9]. To scan a single line, a single pair of laser and photodetector are assembled on a rotational device, creating a 2D LiDAR. If multiple pairs are assembled together, on a rotational device, with different polar angles, the LiDAR is said to be a 3D LiDAR.

These maps, commonly represented as point clouds or mesh clouds, are one of the preferred method for Simultaneous Location and Mapping (SLAM) algorithms, which allows a vehicle without previous knowledge of its surroundings to autonomously navigate them - a crucial task for ADAS on self-driving vehicles.

1.1 LiDAR Interference

TOF LiDARs basic principle implies that when a laser pulse is emitted, three different scenarios are possible, being the first one the only one that produces a valid measurement:

1. The laser pulse returns, due to the reflection of an obstacle;
2. The laser pulse does not return;
3. The laser pulse returns with intensity below the noise floor.

Interference and crosstalk between the pairs of lasers and photodetectors on a LiDAR are mitigated with different firing offsets, or in the case of mutual interference between LiDAR, it is possible to synchronize their firing time using specialized clock signals [1].

However, in a society when self-driving vehicles coexist, another scenario is possible: a LiDAR "A" fires a laser pulse that is received, directly or indirectly, by the photodetector on a LiDAR "B". Since LiDAR "B" measures the distance to an obstacle by measuring the time between the firing and reception of its own laser pulse, the reception of another laser pulse results in an erroneous measure with an unpredictable behavior. If this interference is significant, the reliability of the LiDAR, and consequently autonomous vehicles and ADAS, is seriously undermined due to the incapability to accurately mapping their surroundings.

To the best of the author's knowledge, despite the relevance of the topic to a society of self-driving cars, there are only available the studies conducted by Kim *et al*. [5, 6], which seek to characterize this interference; and by Retterath and Laumeyer [8], seeking to provide an apparatus for reducing the mutual interference of LiDAR sensors on the same vehicle.

Kim *et al*. research is the only study to use two independent 2D LiDARs interfering with each other. Kim *et al*. results indicate that interference has spatial and temporal locality [5] and in any given time, in Kim's setup, a data point has 0.05 % probability of being interfered [5].

1.2 Proposed Work

This research intends to understand the impact of the interference between 3D LiDAR, whose reliability is crucial for self-driving vehicles, consequently expanding Kim's research. Our proposal consists on assessing the interference behavior with the relative distance between LiDARs and the length of the voxel[1] grid used to quantify this interference.

This paper is organized as follows. Section 1 presents the introduction, motivation for this work and briefly summarizes the related work. The second section explains the experimental setup. Section 3 contains the method developed for interference analysis. The results and their discussion is presented on Section 4. Section 5 deliberates on the paper's conclusions.

2 Experimental Setup

To analize the impact of LiDAR interference, two LiDARs were used. One acts as the source LiDAR, which acquires data from its surroundings and the other acts as an interference generator on the data acquired by the first. The source LiDAR is a Velodyne VLP-16, which contains 16 laser beams and is fixed on the table. The LiDAR acting as an interference generator is a Hesai Pandar40, which has 40 lasers, and is fixed on a tripod. Both LiDARs rotate at 600 Rotations Per Minute (RPM).

To capture, manage and analyze the datasets, software was developed in C++, using the Robotic Operative System (ROS) framework and the Point Cloud Library (PCL). ROS was also used for the interaction with the sensors and to allow near real-time operation on a standard laptop computer.

Figure 1 shows a picture of the described setup on one of the test scenarios, a robotic Middle Size League (MSL) soccer field.

3 Methodology

Since it is not possible to distinguish an interfered from a valid measure (from a hardware standpoint, both of them are valid measures), we pro-

[1] A voxel is an element of a 3D grid that is equally spaced, representing a single point.

Figure 1: Experimental setup described on section 2, used for the data presented on this research.

pose a method to distinguish which measures result from LiDAR interference.

The proposed method assumes a static scenario and compares the point clouds with and without interference. First, the LiDARs are positioned and the interference generator LiDAR is off. On these conditions, several point clouds are recorded and merged to create a ground truth model. Then, the LiDAR that causes the interference is switched on and several point clouds are registered.

The first data acquisition is used to generate the ground truth model of the scenario, free from interference, by stitching together the different frames using the Iterative Closest Point (ICP) algorithm. A voxel grid filter is also applied to every frame, to filter out noisy points, reduce the number of points and ensure more uniform point density.

To quantify the interference, each point cloud containing interference is compared with the ground truth model. The occurrence of interference is measured relatively to the total number of voxels and represents the number of modified voxels (i.e., the number of voxels who were occupied and were freed and vice-versa) when comparing the ground truth model with the point cloud containing interference.

4 Results

For a fixed LiDAR height, direction and rotation speed, both LiDARs optical center were aligned and several point clouds were recorded while the interference generator LiDAR was active. Using the method described in Section 3, the quotient of interfered vs total number of voxels was calculated for a relative distance varying meter by meter from 1 to 12 m and considering voxel edge lengths ranging from 10 to 50 centimeters, with steps of 10 cm. The results are presented on figure 2, on the form of a contour graph.

The smaller the voxel edge length (horizontal axis), the higher the number of voxels per point cloud. Analyzing figure 2 we can conclude that the number of voxels affected by interference increases with the decrease of the voxel edge length. If a fixed voxel edge length is considered, one can noticed that the results are more prone to variations with the distance, being this variation more significant at smaller voxel edge lengths.

These results lead us to believe that despite the variation with the distance between the LiDAR, there are other factors that drastically influence the interference. Such analysis is yet to be conducted and it is left for future work.

The experimental results also show that on the worst case scenario, in every 1000 measurements there is an interfered measure (27 points per frame that correspond to 270 points per second). The best case scenario is 1 interfered point for every 100000 points, which is less than a point per second.

5 Conclusion

Interference between TOF LiDAR is a research topic that is yet to receive the attention of the academic community, due to its impact on self-driving

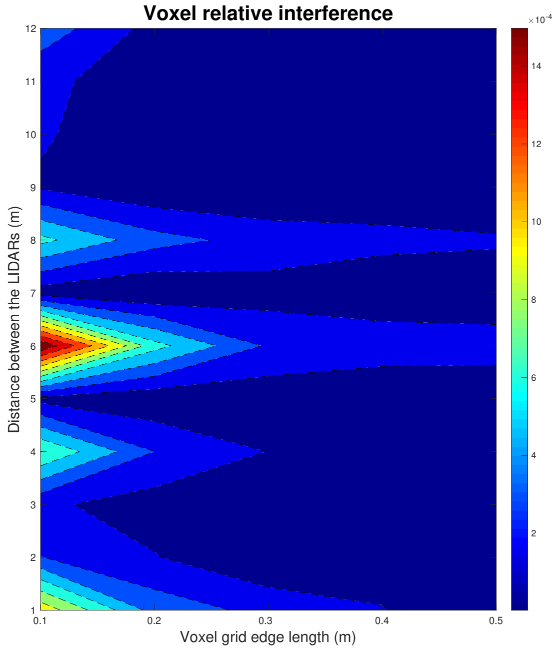

Figure 2: Contour graph of the results. On the horizontal axis the voxel edge length is varied between 0.1 and 0.5 m with steps of 0.1 m. On the vertical axis, the relative distance (keeping the LiDAR orientation with zero azimuthal angle) is varied meter by meter between 1 and 12 meters.

vehicles. The extensive adoption and reliance on LiDAR technology for self-driving vehicles will force the coexistence of these laser sensors on real world scenarios, which, by our findings, will result on mutual interference between LiDARs, causing errors on the measured data.

On this article, a study of the interference between TOF LiDARs is conducted. Previous available results have shown that on 2D LiDARs an error of 1 in 10000 points is expected [5, 6]. Our findings not only extended this study to 3D LiDARs, more common in self-driving vehicles, but also discovered that the severity of errors is highly volatile and can be one order of magnitude higher than previous findings.

Analysis were performed by varying the distance between the LiDARs and by changing the voxel grid edge size. We conclude that the lower the voxel grid edge length, the higher the effects of the interference. Increasing the distance between the LiDAR resulted on a behaviour that has no obvious correlation with the distance. Therefore further investigations are required to identify the main factors influencing mutual interference between LiDARs and to quantify their severity in object detection and recognition.

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