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A methodology for analyzing the impact of crosstalk on LIDAR measurements

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***Abstract*—LIDAR sensors are essential in intelligent transportation systems since they provide high-resolution, dense and precise range measurements. The use of LIDARs is rapidly growing and an increasing number of vehicles equipped with these sensors will share the road in a near future. An unfortunate consequence is that interference between LIDAR devices may occur. Indeed, crosstalk occurs when the laser beam emitted by a LIDAR disturbs the measurement process of another LIDAR. The analysis of the effect of crosstalk is therefore becoming crucial for assessing the performance of LIDAR devices and ensuring the safety of autonomous vehicles. This paper presents a detailed and reproducible methodology for evaluating the impact of crosstalk for LIDARs based on different technologies.**

***Index Terms*—LIDAR, laser scanning, mutual interference, crosstalk, methodology**

I. INTRODUCTION

In recent years, LIght Detection And Ranging (LIDAR) technologies have seen a huge development mainly driven by the intelligent transportation industry. Indeed, LIDAR sensors combined with other existing perception technologies like radar and cameras, are the eyes of future autonomous vehicles [1]–[4]. These sensors provide data about the surrounding environment and enable autonomous vehicles to be aware of the driving situation. Their performance has a critical impact on the safety of the autonomous vehicles on which they are mounted, as well as on the safety of other road users.

Autonomous vehicles require 360° perception. Each sensor technology offers a set of advantages and disadvantages that need to be taken into account to ensure safe perception. LIDAR sensors are seen as offering high-resolution, dense and precise range measurements. They are currently used as a key technology to enable autonomous driving. However, in order to analyze their current maturity, some questions need to be addressed in the context of autonomous intelligent transportation. Perception algorithms are trained to detect moving and static objects and perform ground estimation but usually do not take into account external conditions such as the impact of weather conditions on measurements or other sources of perturbation.

A few studies investigate the effect of weather conditions in LIDAR performance. In [5], an in-depth analysis of automotive LIDAR performance under harsh weather conditions, i.e. heavy rain and dense fog, is presented. [8] investigates the impact of adverse weather conditions, in particular rain and fog, on the detection capabilities of two LIDAR sensors using a testing facility which provides controlled and reproducible conditions. These studies show how the weather conditions affect the detection capabilities of the LIDAR sensors and why it is crucial to properly analyze the external perturbations to design accurate and safe perception systems.

Considering that the road will be shared with other autonomous vehicles equipped with LIDARs, a crosstalk problem could potentially appear, hence impacting the perception performance. Crosstalk mitigation in LIDAR sensors is a current active research topic [6], [7]. Even if commercialized LIDARs adopt technical solutions to reduce the effect of these perturbations, the impact of crosstalk needs to be correctly evaluated to avoid safety problems in LIDARs when used in autonomous vehicles. What happens if several LIDARs share the road? Is there any conflicting situation where LIDAR measurements are affected by other sensors or perturbation sources in the environment?

To answer these questions, this paper presents a methodology for evaluating interference between LIDAR devices. The methodology was applied on five LIDAR devices currently available on the market. The objective is to evaluate the behavior of the devices while interfered by another LIDAR placed in their Field-Of-View.

II. LIDAR DEVICES UNDER TEST

LIDAR sensors scan their surroundings by emitting light beams whose frequency is outside the visible spectrum. After hitting targets, the beams come back to the LIDAR device. The echoes are detected by a photo receiver. The time-of-flight of the beam is measured in order to estimate the distance to the target. When a LIDAR operates, an external system that emits light within a frequency close to that of the LIDAR may create interference or *crosstalk*.

The present paper focuses on the study of crosstalk between two LIDARs. A detailed methodology is proposed for establishing and evaluating crosstalk scenarios. Each scenario is composed of a *LIDAR Under Test (LUT)* located at a known distance from an *assailant LIDAR*. The role of the LUT is to measure the distance to the assailant LIDAR while the latter emits light beams toward the LUT. The objective is to analyze the impact of the assailant on the measurements produced by the LUT.

Five LIDAR devices from different manufacturers have been considered in this study. Due to privacy considerations, the commercial brands are not nominated and the LIDARS are instead numbered from 1 to 5. The sensing principle and technology behind each LIDAR is different. LIDARs 1, 2 and 3 use a rotational motor for scanning. LIDARs 4 and 5 are based on non-rotational technologies and apply different scanning techniques. The wavelengths of the devices vary between 860 nm to 905 nm.

To study the impact of crosstalk on the LIDARs, each sensor is tested under multiple crosstalk scenarios. The next section presents the methodology for establishing such scenarios.

III. CROSSTALK GENERATION METHODOLOGY

The methodology for studying the impact of crosstalk on LIDAR measurements consists in establishing different scenarios where an assailant LIDAR is placed at a known distance from a LUT. The assailant attacks the LUT by generating signals that interfere with the LUT's laser beam. The proposed methodology is composed of the following steps: ground truth setup, LUT and assailant LIDAR positioning, crosstalk generation, points selection and measurement recording.

A. Ground truth setup

The ground truth setup consists in choosing an assailant and placing it at a known position inside the Field-Of-View of the LUT. A test bench composed of a stationary lower part and a mobile bar is used for this purpose. The mobile bar can slide linearly along the top of the lower part. The different LUTs and a laser telemeter are screwed onto the mobile bar, as shown in Fig. 1. The telemeter measures the ground truth distance to the assailant with millimetric precision.

B. LUT and assailant LIDAR positioning

For each scenario, the assailant LIDAR is positioned with respect to the LUT by following two steps. First, the assailant LIDAR is aligned along the laser of the telemeter and is placed at a desired distance. Second, the mobile bar is slid horizontally in order to place the LUT on the former location of the telemeter. This process ensures that the axis of the LUT coincides with the axis of the assailant LIDAR, and the distance between both sensors is equal to the distance previously measured with the telemeter.

C. Crosstalk generation

The assailant is used for perturbing the process of distance estimation that takes place on the LUT. Like any LIDAR, a LUT has two components: an emitter and a receiver. To measure a distance, the emitter emits a laser signal. If the latter hits an obstacle, a part of the emitted signal is reflected back to the receiver. The distance to the obstacle is deduced from the time between the transmitted and backscattered signals. A LIDAR device produces a point cloud by repeating the above measurement process in several directions.

Crosstalk occurs if an external signal has enough power to interfere with the LUT's signal, especially if the signals have similar properties. In the present case, the external signal is generated by the assailant LIDAR. To maximize the occurrence of crosstalk, the beams emitted by the assailant should hit the LUT's receiver. For this purpose, we proceed as follows. First, the assailant is placed at a correct height to ensure that the LUT measures the distance to the assailant's optical window. The optical window is the part of a LIDAR device from which laser beams are transmitted. For this purpose, a cardboard frame is placed at a dozen of centimeters in front of the assailant (see Fig. 1). The cardboard hides the assailant device from the LUT's point of view. The cardboard has however a hole that uncovers only the assailant's optical window.

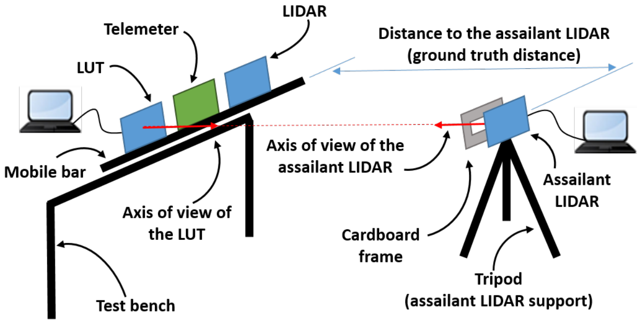

Fig. 1. LUT positioning aligned with the axis of the assailant LIDAR after the ground truth setup.

A software running on a computer connected to the LUT is used to check that the LUT produces points that traverse the cardboard's hole. These points correspond to LUT's laser hits toward the assailant's optical window. The distance of these points is the distance to the assailant estimated by the LUT.

Finally, we ensure that the assailant emits laser beams toward the LUT's optical window. For this purpose, we apply the same technique as above, by using a second cardboard frame with a hole placed at a dozen of centimeters from the LUT and a second computer connected to the assailant.

D. Points selection and measurement recording

After the above process, the cardboard frame in the front of the LUT is removed. The software running on the computer connected to the LUT records LUT's measurements. The software, based on Robotic Operating System (ROS), selects and records only a configurable subset of points within a point cloud. In the present case, only the points that traverse the hole on the cardboard in the front of the assailant LIDAR are recorded.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

To analyze the effect of the crosstalk on each LUT, measurements of several scenarios have been recorded and analyzed. Two LIDARs have been selected to act successively as assailants: LIDAR 1 and LIDAR 2. The two assailants have been placed at four different distances from the LUTs: 5m, 10m, 15m and 20m. A series of 1000 measurements has been recorded for each scenario. The data recorded for each scenario can be statistically classified as hit detection measurements, aberrant values and miss values data. In this paper, for a target placed at distance d, the hit detection data

TABLE I
PERCENTAGE OF TOTAL LOST MEASUREMENTS

	Assailant LIDAR 1			
	5m	**10m**	**15m**	**20m**
LUT 2	52.56%	68.65%	0%	0.45%
LUT 3	0%	0%	0%	0%
LUT 4	0.06%	0.08%	0%	0%
LUT 5	1.31%	0.06%	0%	0%
	Assailant LIDAR 2			
	5m	**10m**	**15m**	**20m**
LUT 1	0%	0%	0%	0%
LUT 3	11.31%	1.18%	0.88%	0.24%
LUT 4	0.12%	0.36%	0.42%	0.77%
LUT 5	29.41%	12.01%	4.78%	3.12%

is defined as the measurements within the set $[\frac{d}{2}, \frac{3d}{2}]$. Aberrant values are the measurements outside the hit detection set. Miss values correspond to laser beams that do not hit any obstacle producing a distance measurement equal to zero. The set of aberrant and miss values is considered as the total lost data.

A. *Crosstalk impact on detection capability*

Firstly, we analyze the impact of crosstalk on the LIDARs detection capability by computing the total lost data. Table I presents the percentage of total lost measurements (with respect to all recorded data) for each scenario. These results show how the crosstalk may significantly deteriorate the detection capabilities of a LIDAR even if the perturbation is caused by a device with a different wavelength as in the case of LUT2 perturbed by the assailant LIDAR 1, with a result of 68% of total lost measurements at 10m. It is worth noting that a LIDAR may be significantly perturbed by another device whose scanning technology is completely different, as is the case of the no-rotational LUT5 with the rotational assailant LIDAR 2.

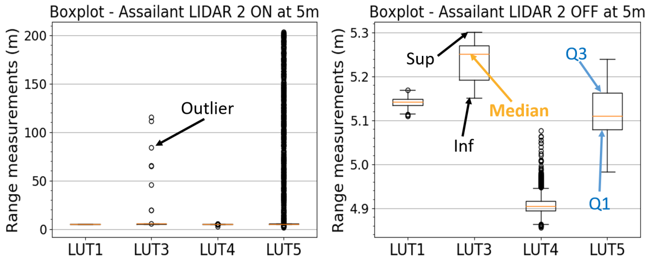

Fig. 2. Boxplot of four LUT measurements when the assailant LIDAR 2 located at 5m (ground truth) is switched on (left) and off (right).

Boxplot information is useful to assess the dispersion of measurements around the median and to identify the scenarios for which there exist aberrant values. The statistical significant values are inside the interval $[Inf, Sup]$ where $Inf = Q1 - 1.5(Q3 - Q1)$, $Sup = Q3 + 1.5(Q3 - Q1)$. $Q1$ and $Q3$ represent the first and third quartile respectively. Values outside this interval are considered outliers. Fig. 2 illustrates the impact of crosstalk on the measurements of four LUTs when the assailant LIDAR 2 is located at a distance of 5m. For the no-crosstalk situation (right) the boxplots show the dispersion of the measurements returned by the LUT, all around the ground truth distance of 5m. When the assailant is switched on (left), the number of aberrant measurements increases considerably for LUT 3 and 5 which are the most affected by the crosstalk effect.

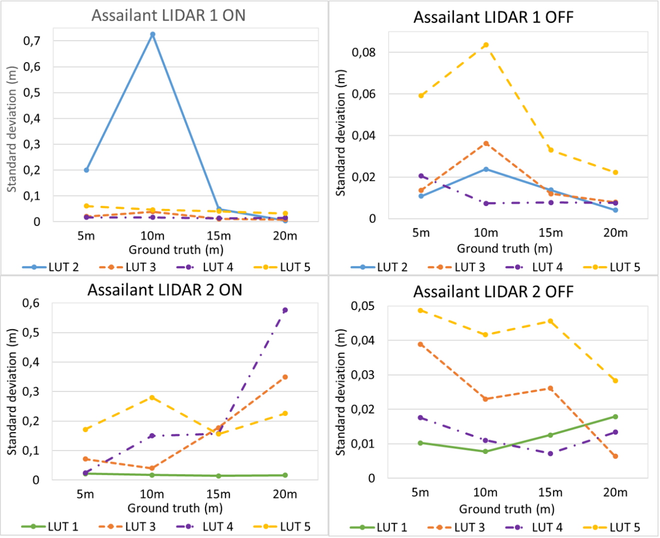

Fig. 3. Standard deviation of the hit detection data of four LUTs for four different scenarios with assailant LIDAR 1 (top) and assailant LIDAR 2 (bottom) under crosstalk (left) and no-crosstalk (right) situations.

B. *Crosstalk impact on detection accuracy*

To evaluate the accuracy of the measurements recorded while the LUT is perturbed by the crosstalk effect, we consider only the hit detection data, i.e., data without miss and aberrant values, for the statistical analysis. Fig. 3 illustrates the difference between the standard deviation computed for the hit detection data of four LUTs when both assailant LIDARs 1 and 2 are switched on and off respectively. The impact of crosstalk on the detection accuracy of the LUT measurements is significant: the standard deviation of all the LUT measurements is greater under the crosstalk situation with both assailants and can even increase by a factor of ten for some LUTs.

V. CONCLUSIONS

This paper presents a detailed and reproducible methodology to evaluate the impact of crosstalk in LIDAR sensors of different technologies. Indeed, this effect must be taken into account due to rapidly growing numbers of Advanced Driver-Assistance Systems (ADAS) and intelligent transportation systems. This paper proposes a methodology to carefully characterize the effect of crosstalk in LIDARs. The results of the study show that crosstalk interference produces a degradation of the detection capabilities of several different LIDAR sensors, even when based on different scanning and sensing technologies. Additionally, this effect can lead to a loss of more than 50% of total measurements at short distances even if the laser wavelength of the two sensors involved is not the same.

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