Measurement 95 (2017) 143–149

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Quantifying the influence of rain in LiDAR performance

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ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form 4 September 2016
Accepted 4 October 2016
Available online 5 October 2016

Keywords:
LiDAR
Autonomous vehicle
Meteorology

ABSTRACT

LiDAR systems emerge as one of the key systems for autonomous vehicles. The present work quantifies the influence of rain in different LiDAR parameters: range, intensity, and number of detected points. Six areas with different target materials are used for the study. Range measurements appear stable even under important rain affectation. The variations are always lower than 20 cm. These variations come from the experimental procedure (averaging of points detected from a surface) and not from the instabilities in the LiDAR detection with rain. The detected LiDAR intensity and the sampled points attenuate with the increasing of rain intensity. Drop size distribution is assumed constant along the study area. The highest decrease in the number of points appears for pavement. However, the intensity returned from pavement is not specially influenced by rain. The rest of the materials show similar trend in the intensity and the number of detected points.

1. Introduction

Mobility is crucial in the right social and economic development of a country. Society strives for safe and efficient mobility at low ecological and economic costs. Driver assistance systems assembled in cars contribute positively to achieve these purposes [1–3]. One example of these solutions began several decades ago with the use of simple technology as the anti-lock braking systems (ABS) and continues nowadays with the GPS positioning on global coordinates, RGB imaging, LiDAR, and advanced computer processing required for the development of autonomous cars [4]. Laser light presents higher values in energy and shorter values in wavelength than radio waves, it reflects better from non-metallic objects and provides mapping advantages of LiDAR over RADAR.

LiDAR systems provide high resolution and accurate 3D maps around the vehicle that allow obstacle detection and support safe navigation [5,6]. Despite the key advances in LIDAR technology, self-driving cars still face many challenges. For autonomous vehicles to succeed in a public environment like a large city, they need to be able to interpret the behavior of human beings (i.e. pedestrians jaywalking, bikers weaving in between traffic, little potholes, ice on the road surface).

LiDAR systems based on time of flight principles emit a short light pulse, which after reflection by the surface of the object is received by the photodetector. The distance is evaluated using the measured time taken by the laser pulse to travel between the point of emission and the target surface [7–10]. According to the principles of interaction between electromagnetic radiation and matter, the reflectance values directly depend on the physical characteristics of the material, the wavelength of the incident radiation, and the distance between the laser emitter and the target. LiDAR systems are traditionally used for surveying to obtain 3D geometry from objects in civil engineering, architecture, mining, or environmental applications [11–14]. The relationship between LiDAR reflectance and the characteristics of the surface has been deeply considered in previous works (i.e. the moisture content, presence of biological crusts on concrete, or the roughness of the surface) [15]. However, the influence of atmospheric conditions on the reliability of LiDAR measurements has not been previously studied. This fact probably comes from the traditional applications of LiDAR measurements in surveying, since the person that operates the system can choose good atmospheric conditions to perform the measurements. The situation radically changes with the integration of LiDAR systems into autonomous vehicles. The vehicle must be able to operate in a safe manner under heavy atmospheric

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http://dx.doi.org/10.1016/j.measurement.2016.10.009

conditions such as fog, rain, or snow. Thus, the experimental data provided in these situations are especially valuable to contribute to the implementation of this technology.

The present work is focused on the influence of rain in LiDAR measurements. The return light intensity, consistency in range measurements, and number of detected points are correlated with the rain intensity. A Velodyne VLP-16 LiDAR is used for the measurements. It is a low cost LiDAR system with high pulse repetition rate, wide angular coverage, and moderate cost. The Velodyne VLP-16 seems to be adequate to applications in autonomous vehicles. Section 2 shows the experimental section, Section 3 the results and discussion, and Section 4 the conclusions.

2. Experimental

2.1. Velodyne VLP-16 LiDAR

The Velodyne VLP-16 (Fig. 1) is a 3D LiDAR. It presents a theoretical range of 100 m, a power consumption of 8 W, weight of 830 g, and footprint of 103 mm × 72 mm. It is especially designed for mobile applications (UAVs, robotics, and driverless cars). It supports 16 simultaneous channels (300,000 points/s), with 360° of horizontal field of view and 30° of vertical field of view (15° up and 15° down). Nominal accuracy is 3 cm, vertical resolution is 2°, and horizontal resolution ranges between 0.1° and 0.4°. Rotation rate ranges between 5 Hz and 20 Hz. Laser wavelength is 903 nm (class 1).

The Velodyne VLP-16 shows IP67 environmental protection. It means that it is totally protected against dust and protected against the effect of water immersion between 15 cm and 1 m. Operating temperature ranges between -10 °C and 60 °C. Dimensions are 103 mm diameter and 72 mm height. Output data are provided by a 100 Mbps Ethernet connection. It contains range, calibrated reflectivity, rotation angle, and synchronized time stamps (μs resolution) to combine the information with other sensing units. No data about LiDAR calibration are provided by the manufacturer. Researches do not implement any complementary calibration procedure.

Fig. 1. Velodyne VLP-16 LiDAR.

2.2. Testing methodology

The testing methodology consists of the measurement of different surfaces around a road under different rain intensities. The selected road belongs to the infrastructures of the University of Vigo in As Lagoas Campus, close to the buildings of the Industrial Engineering School and the Mining Engineering School. Measurements are done along a couple of months (December 2015 and January 2016). The climatology in the region during these months is typically rainy. Rain values are obtained from a meteorological station placed on the Campus that belongs to Meteogalicia (Galician Meteorological Agency) [16]. Drop size distribution is assumed constant along the area under study. The maximum distance between the farthest objects is lower than 100 m, so important differences in drop distribution are no probable. In addition, the high rotation frequency of the scanner provides quasi-simultaneous measurements, which also ensures that there are no differences in rain intensity between the measured elements. All the scans are performed in the same scan position using a geo-mark on the road and a photographic tripod to assembly the Velodyne LiDAR. The following type of materials and surfaces are selected for the study (Fig. 2).

- Area 0. Metal sign with information about the buildings.
- Area 1. Concrete wall.
- Area 2. Stone façade, including windows.
- Area 3. Traffic sign. Retro reflective surface.
- Area 4. Asphalt pavement.
- Area 5. Vertical retro reflective sign to divide the two lanes of the road.

Fig. 3 represents the spectral response of the materials used in this experiment. Data are obtained from the ASTER Spectral Library [17]. Area 0, referred to a metal sign, shows an increasing of the reflectance with the increasing of wavelength. Metal surfaces present high reflectivity in the electromagnetic spectrum because of their electrical properties (free electrons). Besides, their typical polished surfaces produce low diffuse radiation. Area 1 (concrete) depict reflectance values between 30% and 40% up to 2500 nm. Wavelength higher that this value typically exhibit values lower that 10%. Similar trend is observed for area 2 (stone) and area 4 (pavement). The electrical properties of the constructions materials (typically low electrical conductivity) and the surface roughness results in Lambertian reflectors. Lambertian reflectors allow the detection of the radiation at any angle of observation, although decreases the intensity of the detected radiation. Areas 3 and 5 (reflective signs) show the higher values of reflectivity (close to 80%) up to wavelength around 2900 nm. Reflective paintings combine micro-spheres diluted in the painting that help in the radiation reflection. Although there is another reflectance peak around 4600 nm, the reflectance tends to decrease for higher wavelengths as occurs in all the materials except metal.

A software code is developed in C++ to automatically select all the LiDAR points inside a four points pre-selection from each scan and each area of study and obtain the required values (range, LiDAR intensity, and number of points). Range and LiDAR intensity are calculated from the averaging of the points from each segmented area. Table 1 exhibits the average range between the LiDAR and each area under study. Fig. 4 shows an example of one point cloud obtained from the areas of study and the four points pre-selection for each area.