Analysis of Low Cost Sensors Applied to the Detection of Obstacles in High Voltage Towers

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Abstract. In several applications involving autonomous navigation of robotic systems, the selection of the applied sensors is a criterion of extreme importance, allowing the correct identification of obstacles within a safe detection range. Thus, the characterization of the sensors becomes a necessary step in identifying the terms of use and limitations of the different devices analyzed, in order to focus on the correct choice for different applications and scenarios of use. This paper discusses a study about the use and characterization of various ultrasonic sensors and low cost laser sensors applied to the detection of components commonly used in high voltage towers, which have distinct properties and geometries, for means of evaluating a possible use in future autonomous systems through unmanned aerial vehicles. Based on the results obtained, it was possible to identify the characteristics of use of the analyzed sensors in a controlled environment and in an uncontrolled environment, providing vital information for the correct choice of sensors applied to autonomous navigation in high voltage towers scenarios.

Keywords: Ultrasonic sensor · Laser sensor · Power lines components · Sensors properties

1 Introduction

Technological trends on Unmanned Aerial Vehicles (UAVs) indicate that increasingly high-risk operations must be less trusted to human pilots and progressively more to the autonomous capabilities dictated by a reliable sensory system embedded to an UAV, through which the environment around the aerial vehicle is perceived in order to complete its mission [6]. Therefore, any type of robot should have the ability to perform a reliable detection of obstacles and to act in a timely manner to prevent static or dynamic obstacles found in unknown environments [5]. Different technologies can be employed for distance measurements in complex environments. State-of-the-art technologies such as laser scanner sensors

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from manufacturers SICK, Velodyne and Hokuyo offer a good resolution and area of operation, but at a high cost, also requiring the UAVs to be medium or large due to their weight and demanding a high computational performance [8].

Accordingly, an approach involving low cost sensors, such as ultrasonic (US) and laser sensors, can be presented as an attractive alternative applied to sensory systems embedded to UAVs to detect obstacles in electric distribution lines scenarios. The investigation of the laser and US sensors as to their distribution, opening angle, quality of measurements on different object geometries and environmental influences should be investigated in order to obtain parameters of choice of the best types of sensors suitable for high voltage line inspection. In this context, the presented experiment aims to evaluate each proposed sensor in different environmental conditions and to identify their characteristics and behaviors towards commonly used high voltage tower parts. Besides, the conducted tests generated generated results that are estimates of the use of different types of sensors on different types of parts, usually used in high voltage towers, making it possible to establish a relation with the use of these sensors in future robotic navigation systems on UAVs applied to high voltage towers. The structure of this article consists of Sect. 2, where the methodology found in the literature on the use and influences of US and laser sensor architecture are presented. The characteristics of the US and laser sensors are discussed in Sect. 3, and Sect. 4 displays methods adopted to conduct the experiments. Section 5 presents the results obtained and in Sect. 6, final considerations are discussed.

Related Works. Achieving a robust, low-cost sensing system capable of detecting all obstacles present in highly complex scenarios is a difficult task that requires knowing the environment at all times. Many of the collision avoidance systems are directly related to the use of two-dimensional laser range measurement sensors, which are normally used as scanning sensors due to wide performance range. However, laser sensors fail under conditions of high solar incidence and require diffuse reflection to detect objects, unlike US sensors that are not affected by interference from external environments or even under foggy conditions [13]. On the other hand, US sensors have the disadvantage of being susceptible to errors due to variations in air temperature [11] and reading errors consequent to the angle of actuation [2]. Nevertheless, in order to solve most of the detection problems related to laser and US sensors, the combination of these devices is presented in the literature as an advantageous solution for detection of obstacles. The work conducted by Niwa, Watanabe and Nagai, revealed the need to identify the best working angles for ultrasonic sensors to be used in unmanned aerial vehicles, exploring the limitations of using the HC-SR04 ultrasonic sensors and, through the results, indicating the feasibility of its application in UAVs for obstacle detection [9]. Also seen in the contribution by Singh and Borschbach, several interference characteristics of US sensors were explored in outdoor environments. As a result, it was possible to identify some causes of external factors such as angulation, influence of movement and atmospheric pressure so that future sensorial systems can compose an architecture in robotic units to detect obstacles [12]. Approaches involving the characterization of different types of sensors, especially the US and laser sensors, have resulted in the creation of efficient detection and autonomous navigation systems with low cost sensors. As seen in Gageik, Müller and Montenegro, the use of SRF02 ring-architected sensors in a UAV was explored with the intention of detecting obstacles in a 360° range. The results showed that the behavior of 12 ultrasonic sensors when tested on dynamic objects, in this case a moving wall, allowed the UAV to maintain a distance of 1m from the obstacle. However, the system presented very limited detection results in addition to the adoption of a ring distribution whose operating angles generated problems in distance readings. As final observations, the author identifies a real need to use laser-type sensors to compose a more robust detection system [4]. To circumvent the problems, another work carried out by Gageik, Müller and Montenegro, used a low-cost sensory system embedded to an UAV that was composed of several types of sensors, among them 16 laser sensors and 12 US sensors, disposed in a ring architecture and acting as a system detection for collision avoidance. Hence, the final results provided a low-cost sensor architecture which presented operational capabilities of detection and diversion of obstacles, such as people and walls, proving to be a reliable and cheaper system than state-of-the-art systems, in addition to being of easy implementation and low computational load [4]. In the research conducted by Krämer and Kuhnert, different types of approaches related to the interference generated around the electromagnetic field on different types of US sensors were discussed. Besides, as the impact generated by the rotations of the motors near the sonars was evaluated, a scanning laser sensor was implemented, whose range and detection capacity contributed to the effectiveness of the work [8]. Considering that several contributions using US and laser sensor architectures require results that prove their real applicability, the characterization of different sensors incorporated as a unit of detection and prevention of obstacles in UAVs should be considered as a step of extreme importance, which provides a perspective of different types of sensory technologies and their effective application in different scenarios [14].

2 Characteristics of Ultrasonics and Laser Sensors

US sensors have excellent characteristics of versatility as they operate at low power consumption, offer great ranges of performance, and are not affected by light and dust, resulting in a sensor that is extremely useful for outdoor use. In addition, US sensors can measure transparent objects such as glass, which means that the color of the object does not interfere, further increasing the use of US sensors in external navigation systems [6]. However, these sensors are susceptible to reading errors due to variations in air temperature, and the angle of incidence and low directionality, respectively [15]. The operation mode of US sensors is based on a method called Time of Flight (TOF) that works by emitting a high frequency sound pulse by means of an emitter. When colliding with an object, the sound wave is reflected, returning to the ultrasonic sensor receiver. Based on the period of time between the pulse sent and the received pulse, the distance between the sensor and the object [7] is calculated as shown in Eq. (1).

$$Distance = Speed_{sound} * Time/2 \tag{1}$$

However, when more than one US sensor is operating in close proximity, it may occur that one sonars receives the echo of another signal emitted by adjacent sonars, resulting in incorrect readings of distances due to disturbance caused by neighboring sound waves [2]. This phenomenon is known as crosstalk and occurs in almost all types of US sensors, usually in systems that are composed of multiple sensors that adopt the ring architecture, whose goal is to completely cover a given robotic architecture. Environments that have a smooth surface may also contribute to crosstalk reading errors due to wave reflections generated by US sensors [3].

US sensors depend on the speed of sound to calculate the time between the emission of the sound wave and the received echo at the receptor. On the other hand, the speed of sound used in the linear equation applied to ultrasonic sensors may be modified in function of the environment conditions, such as temperature and humidity, to which the sensors are exposed. Consequently, the reading data are affected by inaccuracies caused by variation of environmental conditions. According to the International Standard Atmosphere (ICAO), the speed of sound is 340 m/s under standard environmental conditions (20 °C temperature with 0% humidity and 101.3 kPa). Nonetheless, as the temperature rises, the speed of sound increases approximately 0.6 m/s for each 1 °C. This fluctuation can be observed in the system represented in Eq. 2, where c is the speed of sound (331.4 @ 0 °C), T is the temperature (°C) and H is the value of the environmental relative humidity [11].

$$c = 331.4 + (0.606 * T) + (0,0124 * H) \tag{2}$$

In this context, the implementation of temperature sensors operating collectively to the US sensors is a way to compensate for the disturbances caused by climate change and to grant greater precision in the acquisition of distance readings [11]. As for the laser sensors, their operation method is similar to that of the US sensors, where a pulsating laser beam is emitted and reflected on an object, the time between the emission and the return of the reflected pulse is calculated [1]. Different types of sensors can be applied to detect obstacles, however, rotary sensors of LIDAR (Light Detection and Ranging) type have been outstanding in terms of reading stability and present high degree of applicability, in addition to their low cost.

Laser sensors present greater range of actuation than US sensors, allowing 360° detection of the space surrounding them. Classical methods of detection and prediction of obstacles based on computational vision strategies use a high computational load, which for sensors like YDLidar this is not a problem since it does not depend on that quantity of processing power [10].

3 Choice of Sensors

To achieve the objective of this contribution, different techniques to investigate characteristics of multiple types of ultrasonic and laser sensors must be approached. Thus, information regarding opening angle range, evaluation of performance in internal and external environments, accuracy and measurement errors must be identified. The final composition of the sensors should identify with precision all the objects studied and analyzed in different scenarios. The choice of sensor models, presented in Table 1, is based on their detection range, which should be at least 2 m, a distance that is considered as the minimum necessary to safely detect the components present in a high voltage towers. The cost of the sensors was also considered in order to validate only sensors that are available in the market at a low cost, as presented in Table 1.

Table 1. List of sensors used.

Sensor	Range	Resolution	Current	Price
HC-SR04	2–400 cm	0,3 cm	15 mA	1$
RCW-0001	1–450 cm	1 mm	2.8 mA	1$
US-15	2–400 cm	0,5 mm	2.2 mA	2$
US-16	2–300 cm	3 mm	3.8 mA	2$
VL53L0X	0–200 cm	1 mm	19 mA	5$
VL53L1X	0–400 cm	1 mm	16 mA	15$
YDLidar X4	0–10 m	1 mm	380 mA	99$
LidarLite V3	0–40 m	1 cm	135 mA	130$

4 Experimental Methods

The schematic presented in Fig. 1 illustrates the configurations adopted to conduct the indoor tests, in which, see Fig. 1, the analyzed sensors are positioned in a 15 cm height from the test table and the detected parts (P1–P8) are moved in 10 cm intervals over a 1 mm accuracy measuring tape. As the performance of the sensors are susceptible to environmental conditions, a humidity and temperature sensor (DHT11) was coupled to the US sensory systems in order to compensate variations and the tests happened in diffuse sunlight. Therefore, the assessment was based on different configurations for the US sensors, which were (a) individually with no angle variation, (b) individually with 0°, 15°, 25° and 35° angle apertures and (c) in pairs with 0°, 15°, 25° and 35° angle apertures. Besides, the YDLidar used a 10° setup instead of the default 360° scan.

As stated previously, the objective of this article is to evaluate each sensor used in indoor and outdoor experiments and to identify their characteristics and behaviors towards 7 pieces that commonly compose a high voltage tower as presented in Table 2. In addition, a steel plate (P8) was also evaluated due to its

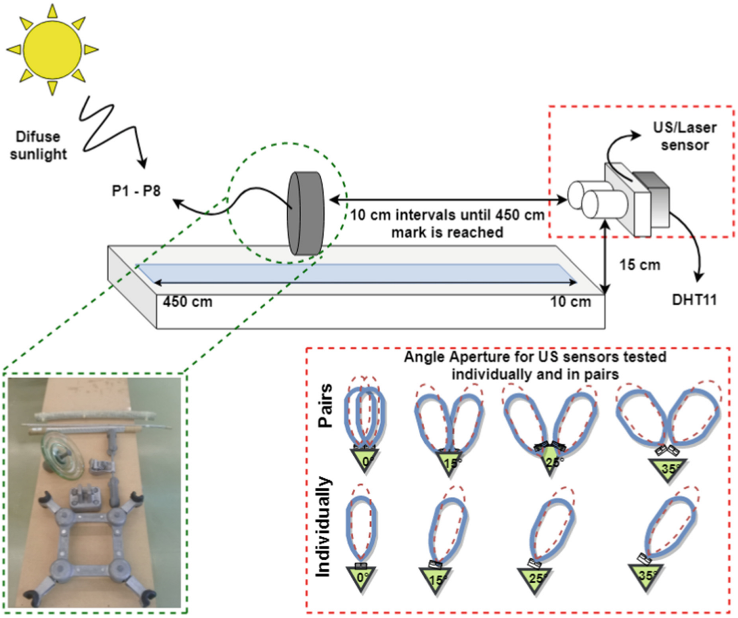

Fig. 1. Experimental procedures.

easy-to-detect geometric shape, which will provide an estimate of the maximum performance of all the sensors used.

The controller board used to process all US sensors data was the Arduino Mega 2560, and the values read were transmitted via serial output to a computer. For every 10 cm covered by the parts used in the tests, 45 samples were taken. For the YDLidar sensor, a raspberry Pi 3B + controller board was selected, through which the developed code stored all its reading information.

Table 2. Components of high voltage towers used during the experiments.

Component	Abbreviation
Aluminum cable 91 AAC	P1
Aluminum cable 61 AAC	P2
Aluminum cable OPGW	P3
Glass insulator	P4
Connector bracket	P5
Vibration damper	P6
Spacer damper	P7
Steel plate	P8

After acquiring preliminary results, the sensors were tested in an external environment, only those that obtained the best results in terms of linearity in the detection of obstacles were selected. It is important to highlight that the studied sensors are low cost elements, which results in the presence of few inaccurate responses. Thus, one of the purposes of this work is to report the functional characteristics of the studied sensors, including their imprecision, as a function of the acquired values from the tested objects.

5 Experimental Results

5.1 Average Obstacle Detection

For sensors that compose obstacle detection systems, a preliminary response of their maximum and minimum operating range becomes essential to estimate their influences and accuracy during operation. In this context, the results, as seen in Fig. 2, reveal the average distance that can be detected on components P3 and P4 towards all sensors used in this experiment within a range of 50 cm to 450 cm. In this preliminary assessment, certain components such as P4 can be detected on a range up to 400 cm by laser sensors and 300 cm by most of the US sensors, which are considered relatively safe distances within an obstacle prediction scenario. In the case of piece P3, several failures were identified, indicating that for a sensory system that must detect cables or lines distributed along an power line, these sensors have unsatisfactory results.

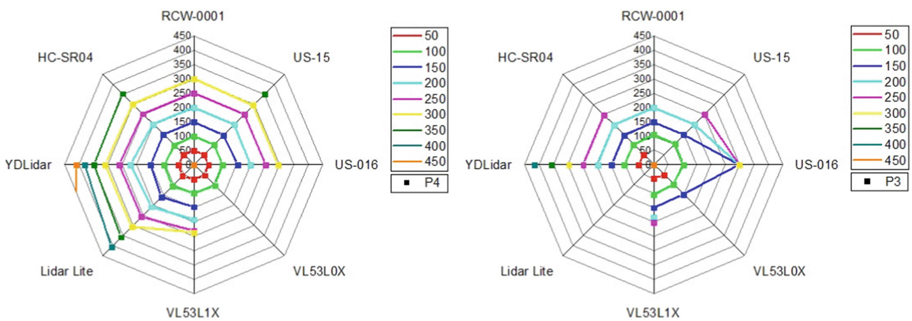

Fig. 2. Average distance of parts P4 and P5.

5.2 Out of Range

The reliability of the sensor to detect obstacles is directly related to the amount of real data samples captured in order to understand the complexity of the scenario in which it is acting. To evaluate the amount of real numerical information generated, 30 samples for each 10 cm covered by the sensors were acquired, identifying the reading error rate, i.e. the amount of "Out of Range" reported when attempting to detect objects, as shown in the Fig. 3.

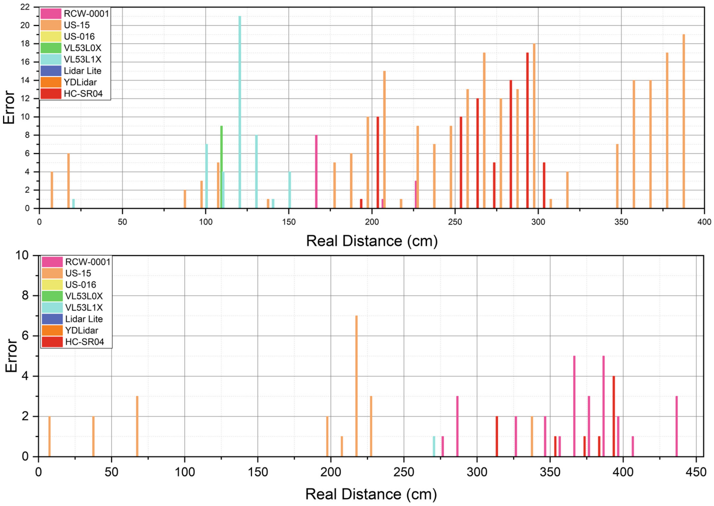

Fig. 3. Number of distance reading errors. on top result of errors in P5 and down P8.

Therefore, this analysis indicates the degree of reliability for each sensor on detecting different materials. Obstacles like the P8 piece presented low repeatability of reading errors. For smaller parts such as P5, several detection failures were identified, especially by the US015 sensor.

5.3 Mean Angular

The evaluation of sensors with respect to their maximum angulation range is important as there is a limit of detection for each type of US sensor. Objects that are outside this range are not detected by the sensor and therefore may represent an accident within an autonomous system. Even in cases where several ultrasonic sensors are being used close to each other, problems related to crosstalk may occur. For this purpose, the general mean responses obtained from each US sensor were investigated individually on opening angles of 15°, 25° and 35°. These angular apertures were controlled by a stepper motor to grant a high degree of angular accuracy, as displayed in Fig. 4.

Subsequently, the same metrics were performed with two US sensors alongside each other (Fig. 5), applying the same angular variation to identify perturbations regarding their proximity during operation. The comparison of responses obtained in tests performed by the sensors individually and by side-by-side revealed problems associated with crosstalk.

The comparison of angular measurements between individually tested and paired US sensors shows that at angles greater than 25° severe distortions in distance measurements occurred, and, based on the proximity between sensors and their angle of aperture, the Crosstalk phenomena is pointed out. In the evaluations of different angles, the results that conferred the best effect with

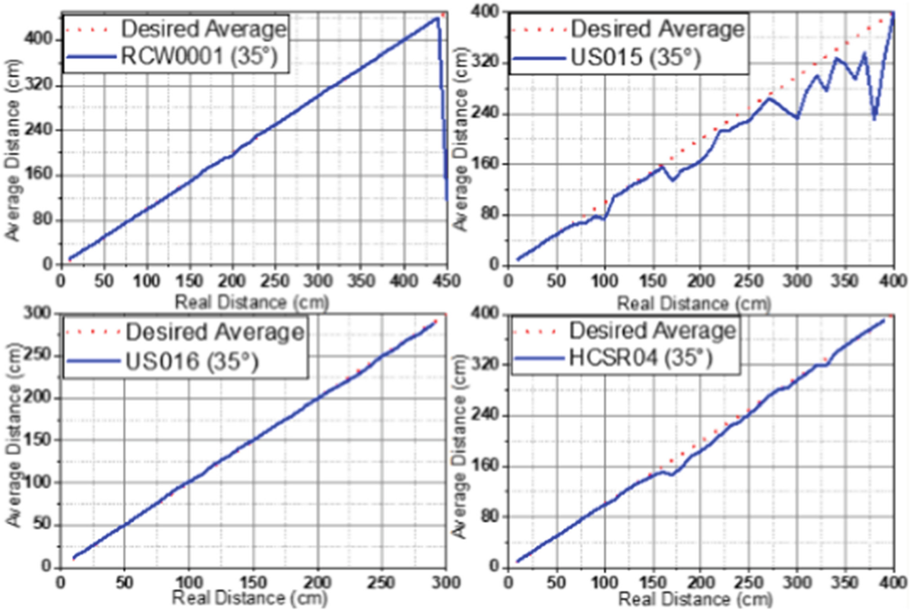

Fig. 4. Angular measurements on individually tested US sensors on P8 object.

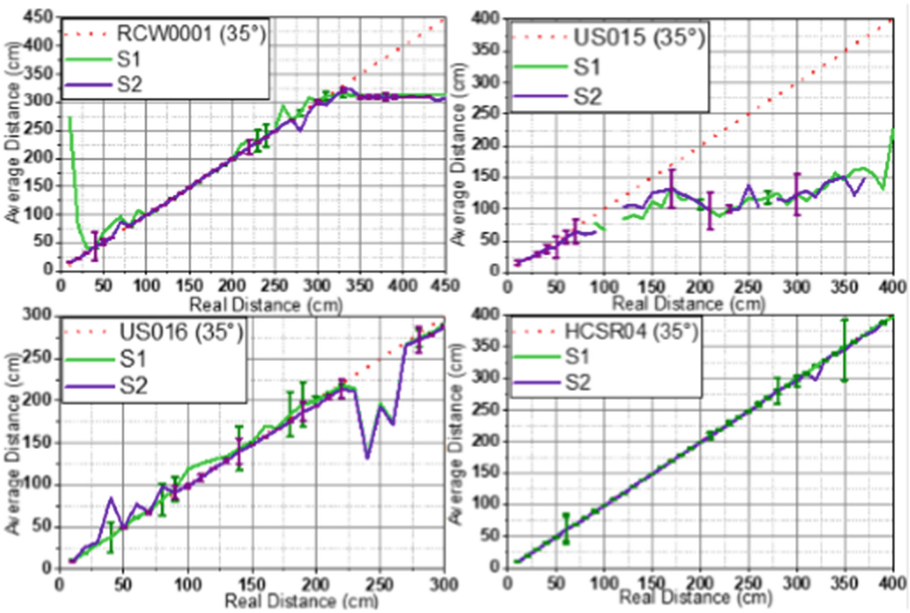

Fig. 5. Angular measurements on US sensors tested in pairs on P8 object.

greater angulation opening were determined by 25° and the sensor that presented the best results was the HC-SR04 sensor and the worst result was given by the US-015.

5.4 Influence on External Environment

Estimating the influence of external environmental conditions on the sensors and analyzing how much their accuracy is affected is extremely important to evaluate the usefulness of the sensory system. To test the external influence, the sensory unit was coupled to an UAV with the sensors that presented the best results based on their generated responses to all the materials tested. On a servo motor, a VL53L1X sensor with two HC-SR04 sensors were placed in a 25° angle and an amount of 400 samples were acquired from a wall in an external environment, performing a scan of 180° and covering intervals of 50 cm until reaching the maximum range of 4 m. In this context, it was possible to evaluate the performance of these sensors when being used in scanning an external environment, as Fig. 6 shows.

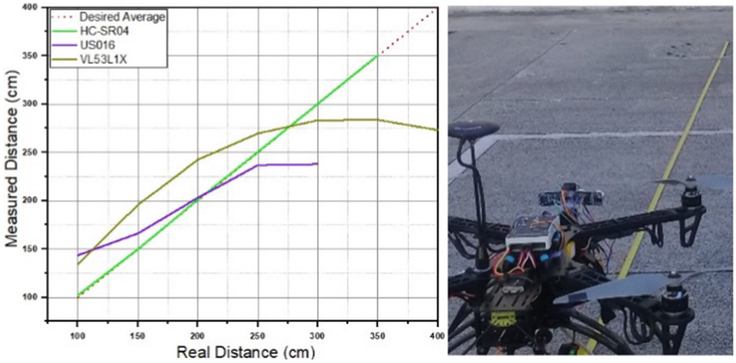

Fig. 6. Average responses generated by the influence of the external environment.

As seen in Fig. 6, the VL53L1X presented a fall in the readings e low linearity due to exposition to external environments, proving its ineffectiveness in a real inspection scenario. On the other hand, the HC-SR04 obtained satisfactory results, since it acquired a great margin of linearity even with constant movement provided by the servo motor, differently from the US-016 sensor, that presented the worst responses in this scenario. When tested in the ground, the YDLidar presented promising results in detection (Fig. 7), obtaining a sample amount of 800 reading points for each meter of distance from the wall with a aperture of 10°, culminating in a total distance of 10 m.

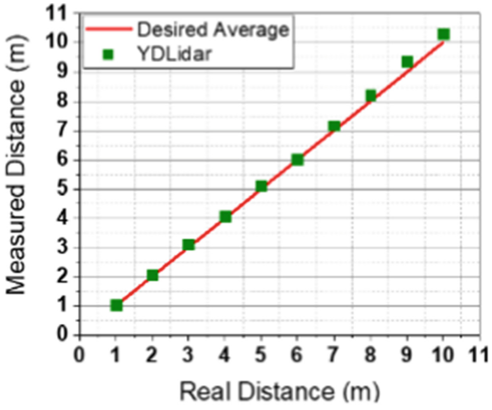

Fig. 7. Average responses generated by YDLidar in external environment.

6 Conclusion

The studies conducted in this work resulted in the conclusion that low cost sensors can be used to detect components of a high voltage tower. Among the US sensors, the HC-SR04 sensor presented the best responses, by maintaining linearity as it collected data correspondent to the distances from the obstacles even with constant movement created by the servo motor. Moreover, it was verified that when the US sensors were disposed close to each other, satisfactory responses from RCW-0001, US-016 and HC-SR04 were obtained in a maximum aperture of 25°. It was established that materials P1, P2 and P3 are the most difficult parts to detect, since they presented responses with values lower than 3 m. As a suggestion for future works, the application of ultrasonic sensors that actuate with a large range could generate better results in the case of the materials cited, but it is important to consider that the actuation spectrum for US sensors is a cone, in order to obtain a actuation area without sunlight interference, differently from the laser sensors. Based on the responses presented by the laser sensors, the YDLidar conferred full detection capabilities in both the internal and external environments, in addition to the lowest quantity of "Out of Range" values, and the high degree of precision when fixed on a determined target. The responses obtained in this contribution can be applied to future projects in sensor architectures, in order to test it in an UAV used to monitor high voltage towers and to gather conclusive information regarding the characterization of the low cost sensors utilized in high voltage tower inspections.

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