Ana I. Pereira · Andrej Košir ·
Florbela P. Fernandes · Maria F. Pacheco ·
João P. Teixeira · Rui P. Lopes (Eds.)

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Optimization, Learning Algorithms and Applications

Second International Conference, OL2A 2022
Póvoa de Varzim, Portugal, October 24–25, 2022
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OL2A INTERNATIONAL CONFERENCE

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Editors
Ana I. Pereira
Instituto Politécnico de Bragança
Bragança, Portugal

Andrej Košir
University of Ljubljana
Ljubljana, Slovenia

Florbela P. Fernandes
Instituto Politécnico de Bragança
Bragança, Portugal

Maria F. Pacheco
Instituto Politécnico de Bragança
Bragança, Portugal

João P. Teixeira
Instituto Politécnico de Bragança
Bragança, Portugal

Rui P. Lopes
Instituto Politécnico de Bragança
Bragança, Portugal

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Preface

This CCIS volume 1754 contains the refereed proceedings of the Second International Conference on Optimization, Learning Algorithms and Applications (OL2A 2022), a hybrid event held during October 24–25, 2022.

OL2A 2022 provided a space for the research community on optimization and learning to get together and share the latest developments, trends, and techniques, as well as to develop new paths and collaborations. The conference had more than three hundred participants in an online and face-to-face environment throughout two days, discussing topics associated with optimization and learning, such as state-of-the-art applications related to multi-objective optimization, optimization for machine learning, robotics, health informatics, data analysis, optimization and learning under uncertainty, and Industry 4.0.

Five special sessions were organized under the following topics: Trends in Engineering Education, Optimization in Control Systems Design, Measurements with the Internet of Things, Advances and Optimization in Cyber-Physical Systems, and Computer Vision Based on Learning Algorithms. The OL2A 2022 program included presentations of 56 accepted papers. All papers were carefully reviewed and selected from 145 submissions in an single-blind process. All the reviews were carefully carried out by a scientific committee of 102 qualified researchers from 21 countries, with each submission receiving at least 3 reviews.

We would like to thank everyone who helped to make OL2A 2022 a success and hope that you enjoy reading this volume.

October 2022

Ana I. Pereira
Andrej Košir
Florbela P. Fernandes
Maria F. Pacheco
João P. Teixeira
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Contents

Sensor Architecture Model for Unmanned Aerial Vehicles Dedicated to Electrical Tower Inspections

Guido S. Berger[1,2,3(✉)], João Braun[1,2,4,9], Alexandre O. Júnior[1,2], José Lima[1,2,4], Milena F. Pinto[7], Ana I. Pereira[1,2], António Valente[3,4], Salviano F. P. Soares[3,4], Lucas C. Rech[5], Álvaro R. Cantieri[6], and Marco A. Wehrmeister[5,8]

[1] Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança, Bragança, Portugal
{guido.berger,jbneto,alexandrejunior,jllima,apereira}@ipb.pt
[2] Laboratório para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC), Instituto Politécnico de Bragança, Bragança, Portugal
[3] Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal
avalente@utad.pt
[4] INESC Technology and Science, Porto, Portugal
[5] Federal University of Technology, Paraná, Curitiba, Brazil
wehrmeister@utfpr.edu.br
[6] Federal Institute of Paraná, Curitiba, Brazil
alvaro.cantieri@ifpr.edu.br
[7] Centro Federal Tecnológica Celso Suckow da Fonseca, Rio de Janeiro, Brazil
milena.pinto@cefet-rj.br
[8] University of Münster, Münster, Germany
wehrmeister@uni-muenster.de
[9] Faculty of Engineering, University of Porto, Porto, Portugal

Abstract. This research proposes positioning obstacle detection sensors by multirotor unmanned aerial vehicles (UAVs) dedicated to detailed inspections in high voltage towers. Different obstacle detection sensors are analyzed to compose a multisensory architecture in a multirotor UAV. The representation of the beam pattern of the sensors is modeled in the CoppeliaSim simulator to analyze the sensors' coverage and detection performance in simulation. A multirotor UAV is designed to carry the same sensor architecture modeled in the simulation. The aircraft is used to perform flights over a deactivated electrical tower, aiming to evaluate the detection performance of the sensory architecture embedded in the aircraft. The results obtained in the simulation were compared with those obtained in a real scenario of electrical inspections. The proposed method achieved its goals as a mechanism to early evaluate the detection capability of different previously characterized sensor architectures used in multirotor UAV for electrical inspections.

Keywords: Unmanned aerial vehicles · Sensor modelling · Robotic simulator · Electrical inspections

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1 Introduction

The use of multirotor unmanned aerial vehicles (UAVs) in most electrical inspection operations carried out nowadays is done through manual commands executed by a ground operator, which determines the distance and positioning of the aircraft concerning the set of electrical cables or the electrical tower infrastructure visually. A second operator on the ground is responsible for analyzing the images of the inspected site in a base station [1].

Although operators on the ground currently conduct the methods of electrical inspections by multirotor UAVs, technological trends indicate that increasingly high-risk operations must rely less on human action and progressively more on the autonomous capabilities of multirotor UAVs. These autonomous capabilities must be dictated by a reliable sensory detection system that senses the UAV's operating environment and automatically avoids potential collisions between the aircraft and obstacles in the inspection environment [2].

With this, the problems generated around visual perspective uncertainties, which generally occur during operations in which the UAV is far from the visual contact of the operator on the ground, would no longer occur through the detection of obstacles by different combinations of sensors positioned strategically over the body of the multirotor UAV [3].

To ensure the detection of multiple obstacles in electrical inspection environments, it is necessary to know the operation of different technologies, seeking to identify which sensors are capable of being applied in this environment. This means that not only the detection capabilities of obstacles belonging to the electrical towers must be evaluated, but also the correct coupling of multiple sensors in the UAV structure, evaluating the regions that can interfere with the detection performance when installed on the aircraft body [4].

This research presents a sensor distribution method for UAVs to detect multiple obstacles in detailed inspection scenarios in high voltage towers. This research is a continuation of the work presented by [5], adding new results that advance the previously proposed theme linked to electrical inspections by multirotor UAVs.

The methodology applied for this research initially evaluates the detection performance of different sensors in front of objects used in high voltage towers. Then, a sensor architecture is modelled in the CoppeliaSim simulator, whose objective is to identify multiple obstacles in a scenario of electrical inspections by UAVs. This sensor architecture is modelled from the beam pattern of the sensors that obtained the best results based on the considerations pointed out by the first set of evaluations.

A sensor architecture, identified as suitable during the simulation, is embedded in a real multirotor UAV designed to fly over a decommissioned electrical tower. Detection data are collected by the sensor architecture in the real environment and compared with the sensory detection data in the simulated environment. The remaining of this work is organized as follows. Section 2 presents the related works and the background of this work. The materials and methodology are presented in Sect. 3. In Sect. 4, the results observed by the experiments are presented, and finally, in Sect. 5, the conclusion and future directions for the work presented are addressed.

2 Related Works

One of the main challenges within the context of autonomous navigation by multirotor UAVs is to be able to autonomously and adaptively avoid the different types of obstacles belonging to the scenario inspected by the aircraft. In this sense, it is vital to understand the working dynamics of different types of sensors when used in multirotor UAVs in multiple obstacle detection tasks [6]. This happens because several factors, such as those related to the exposure environment of the sensors, that can be an element that compromises the detection performance of certain sensory technologies [7].

LASER detection sensors, for example, present great difficulties to be used outdoors because, in conditions of high exposure to sunlight, fog and snow, this type of sensor can present unreliable distance measurements [8]. Most of the works found in the literature use LASER sensors with Time of Flight (ToF) technology in a controlled environment, where there is little or no interference to the sensor. In this way, many works involving applications of LASER sensors in UAVs are used in indoor environments, employing these sensors to perform tasks of multiple obstacle detection and altitude control [1]. LASER measurement sensors based on Time of Flight (ToF) technology emit a pulsating LASER beam, calculating the distance from the obstacle through the time between sending the signal and receiving it. Due to the ability of the LASER pulse to travel roughly at the speed of light in the atmosphere medium, a large number of detection samples per second are obtained, making this type of sensor more accurate compared to ultrasonic sensors [9].

Unlike LASER sensors, ultrasonic sensors (also known as sonar) can detect obstacles even in foggy environments, under direct or indirect sunlight exposure, and are widely used in multirotor UAVs for indoors or outdoors operations [10]. Like LASER sensors, ultrasonic sensors work using the Time Of Flight method, measuring the time taken by sending and receiving a high-frequency sound wave that operates at the speed of sound. When this sound wave hits an obstacle, it returns to the ultrasonic sensor, which converts it into an electrical signal, interpreting this signal as a measure of distance [9].

However, ultrasonic sensors in outdoor environments are also affected, where there is no local temperature control, where the speed of sound increases by approximately 0.6 m/s for every 1°C rise. This increase in the propagation speed of the sound wave can induce inaccuracies in the distance measurements obtained by the ultrasonic sensor, generating detection uncertainties about the target obstacle. To permanently establish the same propagation speed of sound waves, temperature sensors are incorporated into the sonar control system to analyze the ambient temperature variation. Through this feedback, the ultrasonic sensor control system can maintain the same speed of sending the sound wave [11].

Typically, ultrasonic and LASER sensors are used together on the structure of the multirotor UAV because they present distinct advantages in obstacle detection [10]. However, certain regions in the multirotor structure can be noise sources for certain types of sensors, minimizing or nullifying their obstacle detection capabilities. In regions located on the extremities of multirotor UAVs, sonars can present unreliable distance measurements due to the constant vibrations generated by the engines or the gust of wind caused by the rotation of the propellers [12].

LASER scanner sensors with LiDAR technology can also fail if attached to regions of the UAV that experience constant vibrations, especially when fitted over the ends of the multirotor. In this case, the vibration can cause discontinuity on the point cloud produced by the sensor on the target objects [13]. Other strategies found in the literature adopt multiple ultrasonic sensors grouped around the UAV to create a vast obstacle detection region. However, this sensory arrangement allows the emergence of the crosstalk effect. The crosstalk effect occurs when multiple sonars are very close to each other, causing the beam pattern of the sensors to overlap, and with that, the signal sent by a given sensor ends up being received by the adjacent sensor, which can lead to failures in the detection of obstacles [14]. Figure 1 illustrates the ultrasonic sensor's beam pattern and how the lobes' overlapping between sonars is represented, causing the crosstalk effect.

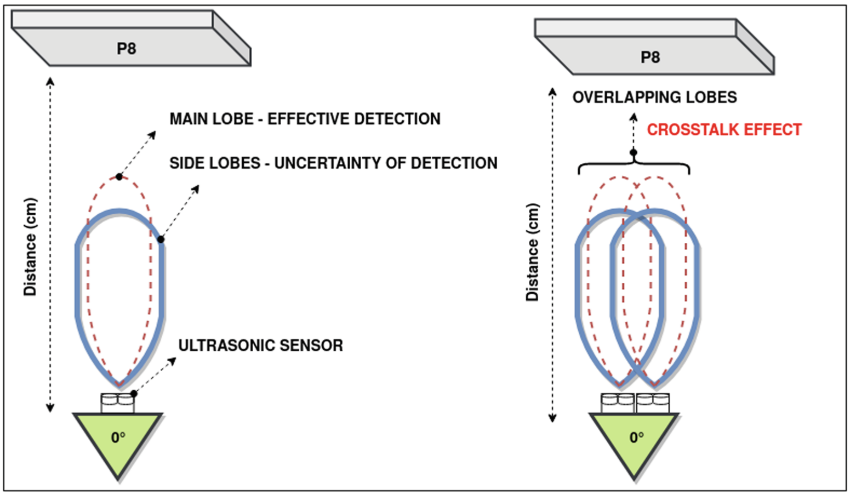

Fig. 1. Crosstalk effect by overlapping the lobes of ultrasonic sensors.

In other cases, few ultrasonic sensors are used on the structure of the UAV to detect multiple obstacles. In this case, objects that are not perpendicular to the acoustic axis of the ultrasonic sensor, where the effective detection by the sensor occurs, may not be correctly detected, generating unreliable distance measurements and thus characterizing problems related to angular uncertainty [6].

3 Materials and Methods

This chapter presents the methodology adopted for the development of this research. The first step is centred on the characterization of different types of sensory devices, evaluating detection performance issues based on their technological characteristics and data extracted from their manufacturing manuals. A set of components belonging to a high voltage tower is used as a target to determine which sensors have the best detection performance. The characteristics of the sensors, such as the maximum and minimum detection ranges, conditions of use in indoor and outdoor environments and capabilities to identify obstacles of different properties and geometries, are raised and discussed. The adversities in the sensor application environment, such as high sun exposure, vibration and temperature change, are explored to select sensors that are unaffected by this. At the end of the first step, it will be possible to determine the best sensors to be applied in the electrical inspection environment.

These sensors are then modelled in a second step in the CoppeliaSim simulator, representing their beam pattern based on the data collected by the sensory characterization and the data contained in their manufacturing manuals. A sensor architecture is modelled on a multirotor UAV, considering the sensory coverage over the aircraft body and positioning the sensors so that they are not affected by crosstalk and angular uncertainty-related issues. In this virtual scenario, the sensor architecture is used to identify the base of a high voltage tower and the set of electrical cables. Finally, in the third step, an actual multirotor UAV is developed containing the same sensor architecture modelled in the CoppeliaSim simulator. This UAV is then used to fly over a deactivated actual electrical tower, collecting information from the sensory architecture of the electrical tower base and electrical cable assembly. Figure 2 illustrates the methodological steps adopted in this research.

3.1 Characterization of Sensors in a Controlled Environment

The objective of the evaluation in a controlled environment is to find the sensors that present detection results from at least 2 m away. This distance was chosen considering the minimum safety distance of a UAV when used in electrical inspections. These sensors were chosen because they are small, easy to integrate into multirotor UAVs, and energy-efficient. The detection sensors used in this research are shown in Table 1.

The components used in the experiment are parts used in high voltage towers with a non-uniform geometry. Unlike the other components, the metal plate (P8) was used because it presents a geometry that is easy to detect by the sensors, allowing the comparison of the response curves of an object that is easy to perceive compared to other objects that have complex geometries for perception. The components used in this step are shown in Fig. 3.

To conduct the experiments in a controlled environment, the following procedures were adopted:

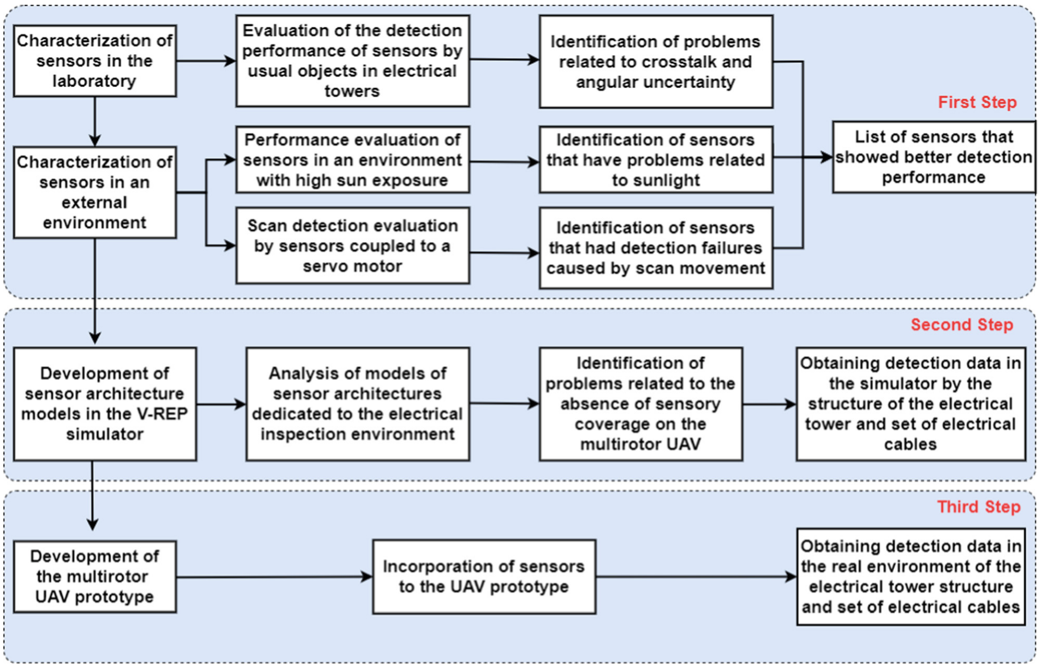

Fig. 2. Task flow adopted the methodology.

Table 1. Maximum and minimum detection capabilities of the sensors.

Sensor	Range(cm)	Resolution (mm)	Current (mA)	Price ($)
HC-SR04	2-400	3	15	1
RCW-0001	1-450	1	2.8	1
US-15	2-400	0.5	2.2	2
US-16	2-300	3	3.8	2
VL53L0X	0-200	1	19	5
VL53L1X	0-400	1	16	15
YDLiDAR X4	0-1000	1	380	99
LiDARLite V3	0-4000	10	135	130

- All objects used as targets have their orientation always in front of the sensors. The positioning of objects is done manually and guided by a tape measure with a precision of 1 mm.
- All ultrasonic sensors used a temperature and humidity sensor (DHT11) to correct variations in environmental conditions.
- All objects used in the experiments were manually positioned in front of the sensors every 10 cm until they reached a distance of 450 cm. For every 10 cm of distance between the object and the sensor, 45 detection samples are collected.
- The sweep angle of the YDLiDAR X4 sensor was set to 10°.

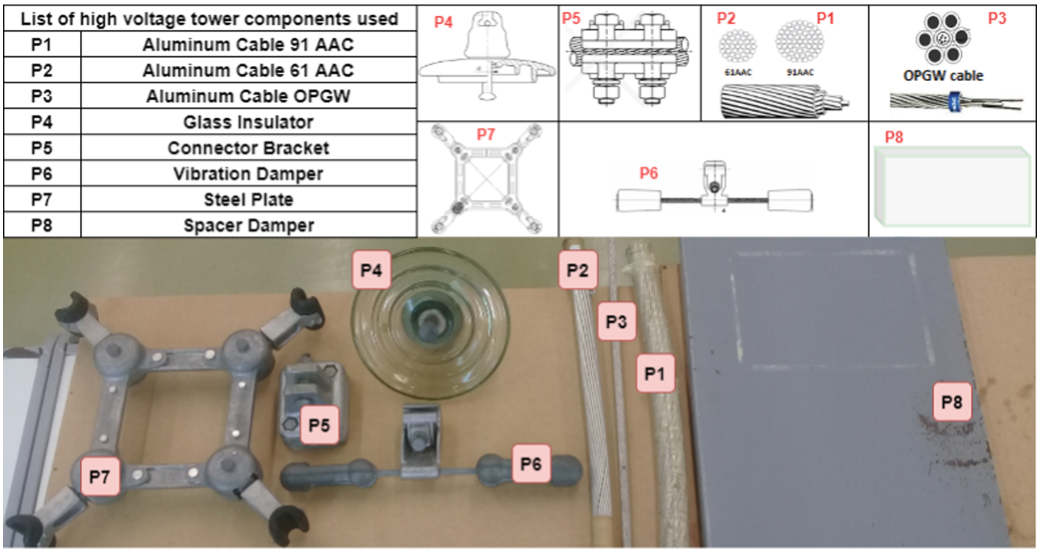

Fig. 3. Components of a high voltage tower used in the research.

– Data from all sensors, except for YDLidar, were obtained from a data acquisition system implemented in an Arduino Mega 2560 controller board. YDLidar data were obtained from a data acquisition system implemented in Raspberry Pi.

With the dataset extracted in this first evaluation, the simple arithmetic mean and variance of the detection values of the sensors were stored. Then, tests were performed only with the ultrasonic sensors to identify the range of detections used in different angular positions. This evaluation sought to determine the limit angle for the detection of ultrasonic sensors when used individually or grouped without problems related to the crosstalk effect and angular uncertainty. For this, each ultrasonic sensor was tested individually at 0° and subsequently at angles of 15°, 25° and 35° over the P8 (metal plate) object, storing an amount of 45 samples for every 10 cm traveled, until reaching the maximum detection distance of the sensors on the target object.

Then, angular detection assessments were performed using ultrasonic sensors in pairs, following the same methodological procedures adopted for the individual evaluation. For this, an 8BYJ-48 stepper motor was coupled to each ultrasonic sensor, aiming at precision and synchronization between the positions of 15°, 25° and 35° as illustrated in Fig. 4.

3.2 Characterization of Sensors in an External Environment

The tests conducted outdoors were carried out during times of high solar incidence, during the early afternoon. The main objective of this evaluation was to analyze whether LASER sensors have detection capabilities even under strong sunlight. Initially, LASER sensors with a longer detection range were used, i.e.,

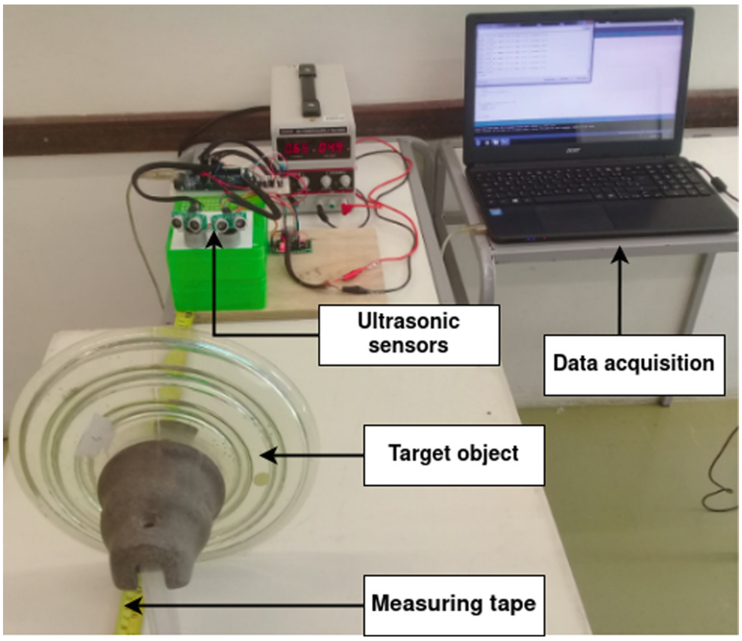

Fig. 4. Evaluation of angular detection by ultrasonic sensors.

the YDLiDAR X4 and LiDAR Lite V3 sensors, to detect a wall at a maximum distance of up to 10 m. A measuring tape was used to guide the sensors at each 1-m displacement in front of the target. For each meter travelled, 400 detection samples were acquired.

In the second sequence of tests involving ultrasonic and LASER sensors with lower detection capacity, tests were carried out to analyze the performance of the sensors when used in constant motion. For this, a servo motor was used as a base to couple each sensor, providing a scan detection range of 180°, detecting a wall that was used as a target. A tape measure was used to guide the positioning of the sensors on the target. The scanning detection evaluation generated an amount of 400 samples for each 1 m of distance travelled between the sensors and the mark, reaching a maximum distance of 4 m.

3.3 Multirotor UAV Prototype

The multirotor UAV was developed with the purpose of validating a sensor distribution model that detects obstacles in an electrical tower. For this, a small aircraft was developed with the ability to perform controlled and stable flights.

3.4 Model of Sensor Architecture

By the CoppeliaSim simulator, different beam patterns are modelled, representing the detection performance of the sensors integrated with a multirotor UAV. The beam pattern model is built by correlating the results presented by the sensory characterization versus the detection distances informed in the sensor manufacturing manual. From this information, the size of the sensor beam pattern is modeled, as illustrated in Fig. 5.

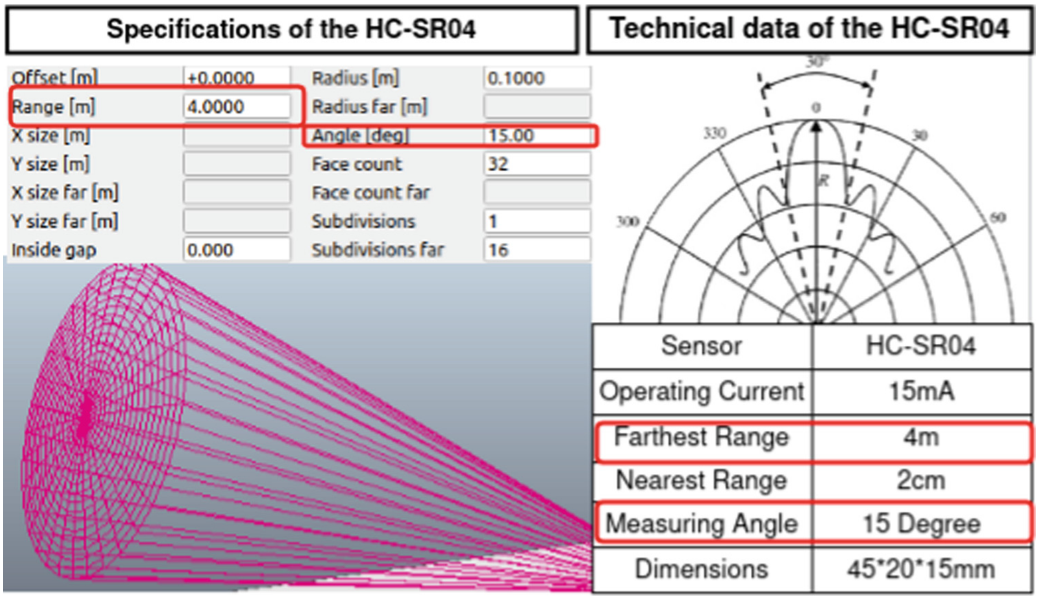

Fig. 5. Beam pattern of the HC-SR04 sensor modeled on the simulator.

4 Results

This section presents the results obtained by the methodology proposed in this research.

4.1 Result of the Characteristics of the Sensors in a Controlled Environment

The responses generated by the laboratory tests helped identify the types of sensors with the greatest detection range on the different types of components existing in high voltage towers. Among all the components evaluated in this first experiment, the object P3 (OPGW cable) was not properly detected by most sensors, which is the object of greater detection complexity evaluated in this experiment. In an overview, it is possible to observe in Fig. 6 the sensor detection relationship between object P8 (metal plate) and object P3. As it is a thin object, the OPGW cable presented great difficulties in being detected by most sensors in this evaluation. Unlike object P3, the metal plate proved easy to detect due to its simple and uniform geometry, making it possible to analyze the maximum detection performance of the sensors involved in this research.

The HC-SR04 sensor presented the best detection performance over the set of electrical cables (P1, P2 and P3), perceiving obstacles at a range greater

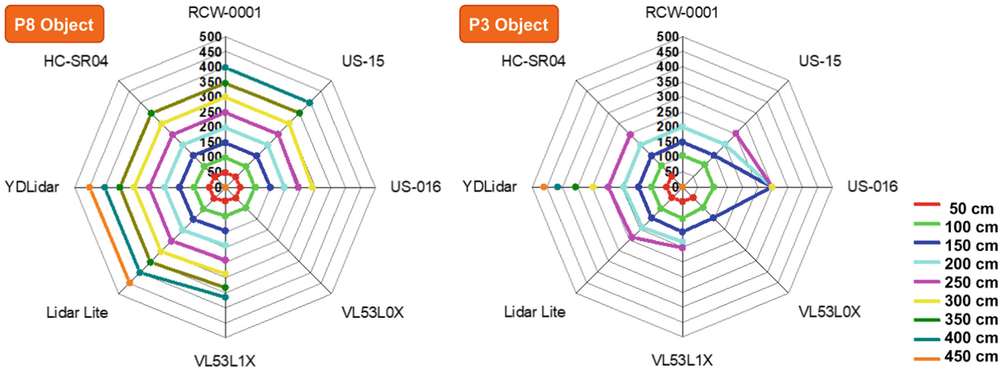

Fig. 6. Preliminary results obtained during tests in a controlled environment.

than 2 m away, as shown in Fig. 7. Based on these responses, it was possible to estimate that in the face of a scenario of detection of power transmission lines, a multirotor UAV developed for this application may have the ability to detect objects of thin thickness at a distance considered safe, taking into account that the detection will occur at a distance of at least 2 m.

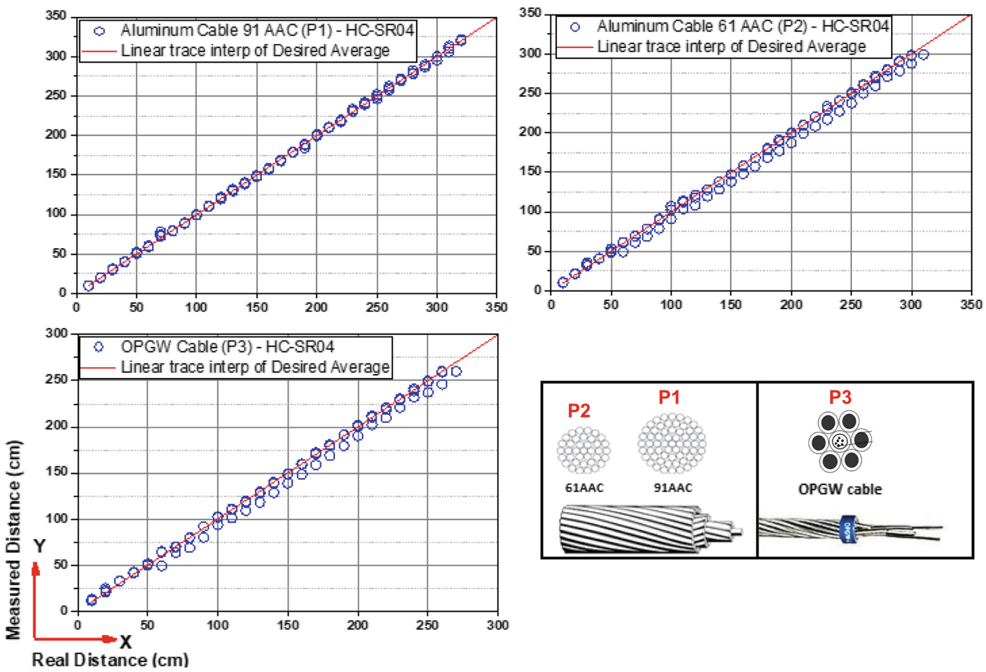

Fig. 7. Detection results of the HC-SR04 sensor on electrical cables.

The results generated from the comparison between the individual detection and the pairs of the ultrasonic sensors on the P8 object show that before the positioning between 0° and 15°, problems related to the crosstalk effect introduced errors of detection on the P8 (metal plate) object. The intensification of the crosstalk effect occurred when positioned at 0°, with the total superposition of the lobes of the ultrasonic sensors. It was identified that with the positioning of 25°, detection results were produced between ultrasonic sensors with greater proximity to the desired average distance. Problems related to angular uncertainty were generated from the positioning of 35°. Overall, the HC-SR04 sensor presented the best detection performance, identifying obstacles at a distance range of more than 2 m.

4.2 Sensory Results in External Environment

The results presented in this evaluation helped to identify which sensors are not affected by sunlight, temperature variation and vibration generated by a servo motor. Figure 8 shows the results obtained by the sensors evaluated in the external environment, indicating that the YDLiDAR X4 sensor has a null detection range under high sunlight. Unlike the YDLiDAR X4 sensor, the LiDARLite V3 LASER sensor could identify the target even under high sunlight, presenting characteristics that allow it to detect targets regardless of lighting conditions. Among the shortest range sensors, represented by the HC-SR04, US16, and VL53L1X, the HC-SR04 sensor presented the best detection results.

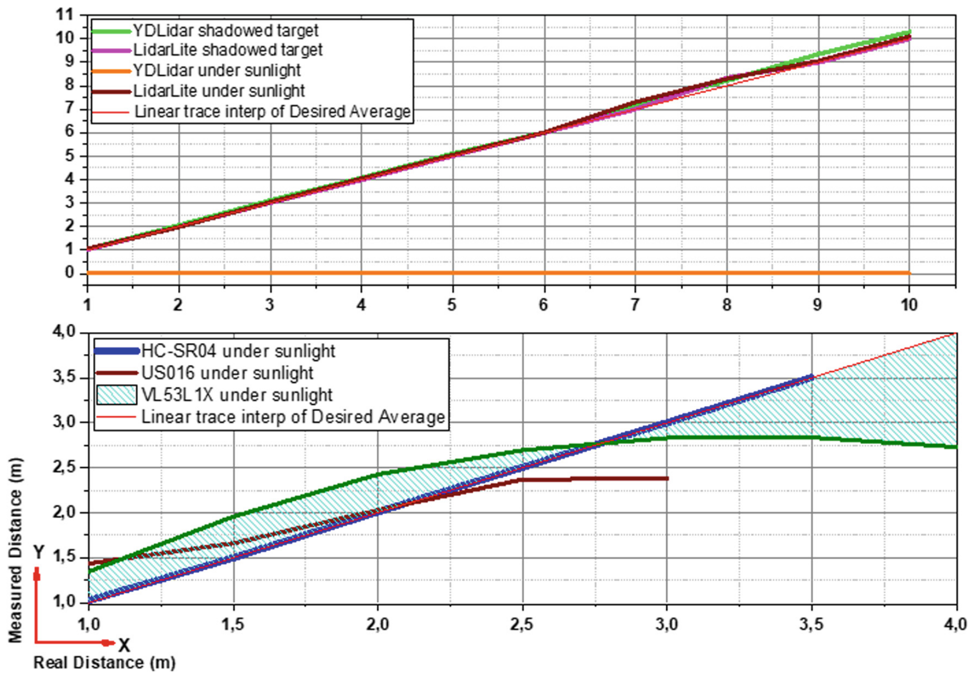

Fig. 8. Results of sensory detection obtained in the external environment.

4.3 Sensor Achitecture for the UAV Prototype

It was identified by the results obtained in Sect. 4.2 that the HC-SR04 and LiDARLite V3 sensors have the characteristics required to compose the different models of sensor architectures together with the CoppeliaSim simulator. Other sensors used in the experiments did not meet the expected requirements, these being (I): detection capacity greater than 2 m away, (II): identification of multiplThe results presented show a relationship between the values obtained in the simulation and the real environment, indicating similarity between the detection ranges of the sensors applied in the electrical inspection environment. In future works, the objective is to integrate artificial intelligence systems applied to autonomous navigation based on the sensory architecture used in this research. In addition, it will be possible to add new sensors in other regions of the UAV aiming for omnidirectional detection systems obstacles, (III): identification of thin obstacles such as electrical cables, (VI): be able to identify obstacles even under high sunlight, (V): be able to identify obstacles even in constant vibration.

The sensory architecture model developed in the simulator is composed of 4 HC-SR04 ultrasonic sensors that are positioned on the front end of the UAV and a LASER LiDAR Lite V3 sensor. The ultrasonic sensors are separated from each other in an angular position of 25°, a configuration that presented the best results during the sensory characterization steps. In this architectural model developed, both the HC-SR04 and LiDARLite V3 sensors perform a sweeping horizontal movement at 180°, making it possible to carry out detections both in the frontal and lateral regions of the multirotor. Figure 9 presents (a) the architectural model defined as ideal and used in the simulated environment; (b) the architectural model defined as ideal coupled to the actual UAV.

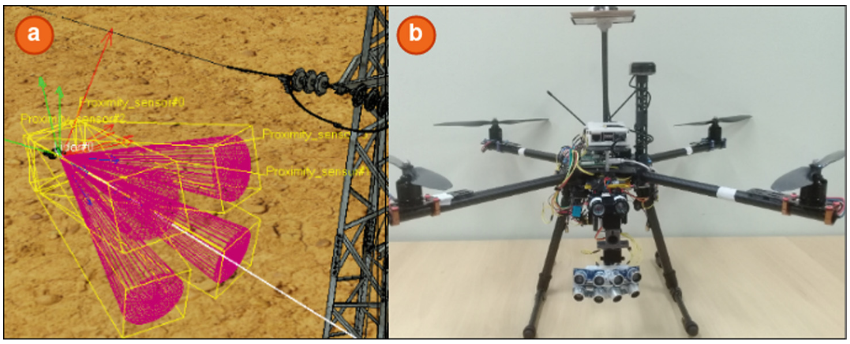

Fig. 9. Sensor architecture model defined.

For data acquisition in the simulated environment, the UAV was positioned just in front of an electrical tower, collecting a set of 400 samples of the tower structure and moving every one meter of distance until it covered the range of 10 m. It also evaluated in the simulator the ability to detect the set of electrical cables by the UAV, collecting detection information within the range of 1 to 4 m away.

4.4 Comparison of Simulated Data to Actual Data

Following the same procedures adopted in the simulation, the actual UAV was used to fly, remotely controlled, over a set of high voltage towers, obtaining detection data from the infrastructure of the electrical tower and the group of transmission lines. In this test environment, a tape measure was used to mark the actual positioning in relation to the aircraft. Three LASER indicators are attached to the UAV to point out the approximate location of the aircraft in relation to the tape measure. Figure 10 illustrates in (a) system to assist in viewing the positioning of the UAV; (b) test environment; (c) acquisition of tower infrastructure data; (d) data acquisition of the electrical cable assembly.

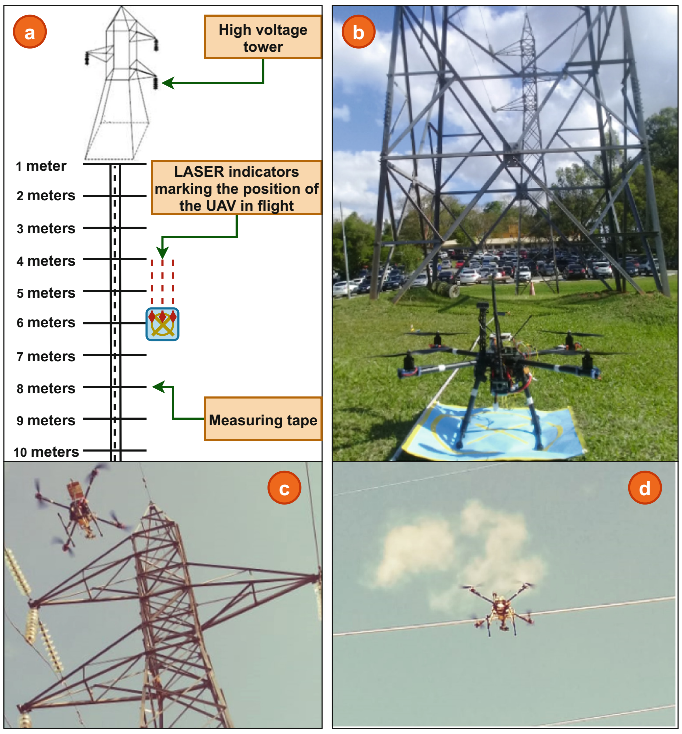

Fig. 10. Procedures and tests performed on a real electrical tower.

The results presented by the sensory detection in a simulated environment were closely related to the actual detection values. During the simulation, all four sensors could adequately identify the base of the electrical tower within the determined distance range, from 100 cm to 400 cm. When comparing with the values of sensory detection obtained in a real environment, it can be seen that, in general, there were detection variations around 50 cm, except for HC-SR04 (2) which indicated a variation around 100 cm. The detection variation of the ultrasonic sensors was because the structure of the actual electric tower has a complex geometry, being hollow and not uniform. Figure 11 presents the results obtained by the sensory detection of the HC-SR04 sensor on the structure of the

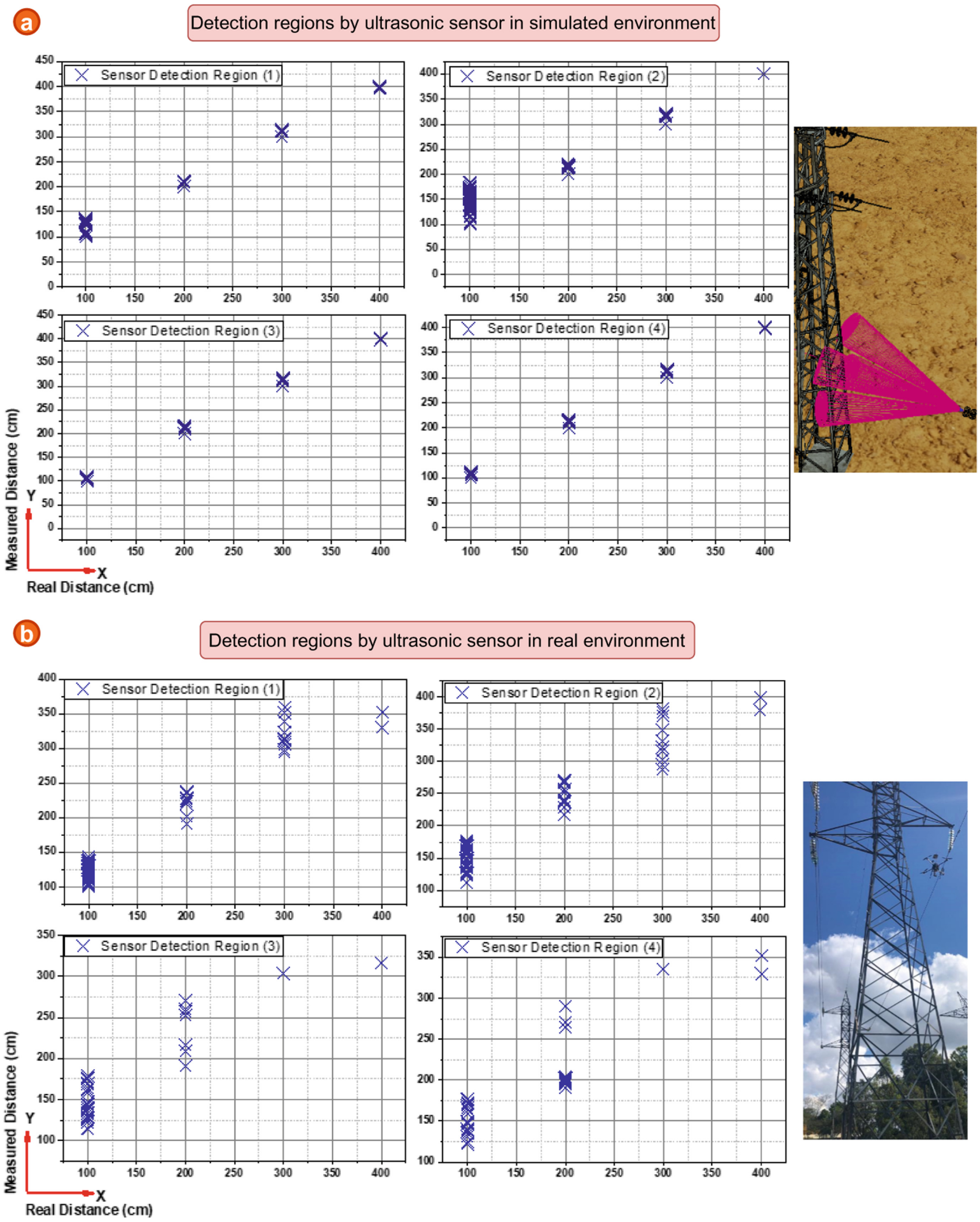

Fig. 11. Detection results of HC-SR04 sensors in simulated and real environments.

electrical tower, wherein (a) the results obtained in the simulation are presented; (b) results obtained in a real environment.

As with the HC-SR04 ultrasonic sensors, the LASER LiDAR lite V3 sensor presented detection results close to the desired distance ranges, accurately detecting the structure of the electrical tower up to the 10-m distance mark in high sunlight. For the acquisition of detection data from the set of electrical cables, the UAV initially remained positioned in front of the electrical lines at approximately 1 m away, collecting detection information by performing smooth movements away from the transmission lines. The values obtained by the sensors were filtered so that only detection data within the range of 100 cm to 400 cm were kept.

The results show that the HC-SR04 sensor can detect the set of electrical cables, which are constituted in the real scenario by the 91 AAC cable, that is, the P1 object. The number of detection points obtained by the set of ultrasonic sensors, identifying the set of electrical cables at distances greater than 300 cm, shows the ability to detect thin objects at a safe distance by the UAV. In the simulated scenario, the detection results by the set of sensors HC-SR04 presented capacities similar to those obtained by the real environment.

5 Conclusions and Future Work

The main objective of this research was to propose a sensor distribution method based on geometric representations. With this, it is possible to preliminarily visualize the detection and performance behaviour of different types of sensor architectures in multirotor UAVs. Based on the technical characteristics of the sensors that presented the best results in this study, namely HC-SR04 and LiDAR Lite V3, a sensor architecture modelled through the CoppeliaSim simulator was proposed, with the ability to identify the base and sets of electrical cables of a high tower voltage at distances greater than 2 m.

The results of this research show that multiple ultrasonic sensors, which operate 25° apart, do not present problems related to the *crosstalk* effect due to the distance between the beam pattern of each ultrasonic sensor. Problems related to angular uncertainty were generated from the positioning of 35° between ultrasonic sensors and less than 25° when causing the crosstalk effect. Sensor detection evaluations in outdoor environments showed that low-power LASER sensors, such as the YDLiDAR X4 sensor, cannot detect obstacles in the face of high sun exposure.

The results presented show a relationship between the values obtained in the simulation and the real environment, indicating similarity between the detection ranges of the sensors applied in the electrical inspection environment. In future works, the objective is to integrate artificial intelligence systems applied to autonomous navigation based on the sensory architecture used in this research. In addition, it will be possible to add new sensors in other regions of the UAV aiming for omnidirectional detection systems.

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