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Conception and implementation of a call system for autonomous mobile robot

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Abstract - Assistive robots are designed to help people in daily life in healthcare institutions and to facilitate repetitive or difficult tasks. In order to develop the performances of the assistance robot and to reinforce people's autonomy in nursing home, this project consists in developing a robot able to answer the user's call. To this end, Ultra Wide Band (UWB) technology is used to determine the position of the calling system. Initialization of the robot position, which is mandatory for autonomous navigation to the calling system, is computed through UWB and Light Detection and ranging (LiDAR) scanning sensors. Thus, the robot moves once the person calls the robot by a radio remote control while avoiding obstacles in an indoor environment. The resolution of the problem has been well confirmed by simulations and real tests in the laboratory. We describe a new feature aimed at making this mobile robot more useful to aging adults in healthcare institutions like rehabilitation centre or nursing homes with robot remote control.

Keywords: Assistant robot, UWB, LiDAR, ROS, Autonomous Navigation, Indoor Localization.

I. INTRODUCTION

Robotics started the explosion of research topics in the last century. There are several types of robots such as intervention robots, industrial robots, lidic robots and service robots, etc. Service robotics first developed around intervention robotics, particularly in the nuclear field since the 1950s with remote-controlled mobiles. A service robot is a mechanical system that enables tasks to be performed to simplify the person's daily life [1]. It is used to help people with repetitive or difficult tasks, and to assist people in need. Service robots, as described by the International Organization for Standardization, are robotic solutions "that perform useful tasks for humans or equipment excluding industrial automation applications" [2].

Mobile service robots acquire new levels of autonomy thanks to numerous technologies, such as new sensors and microlocalization technologies. Mobile robots use sensors and software for both control and perception. It is a function of defining where and how the robot should move. Even with problems still to be solved, the SLAM (Simultaneous Localization and Mapping) technique is still at the basis of the navigation requirements of robots and provides a solution for the localization and mapping of mobile robots [3]. In the near

future, the combination of deep learning and visual SLAM will improve robot positioning. The integration of semantic information in SLAM algorithms is the subject of numerous studies [4]. Perception allows the robot to understand and react to its environment. With Lidar sensor for safe detection of persons, the robots can be more aware of their surroundings, to move smoothly and efficiently. Mobile robots are able to navigate dynamically, have an environmental awareness that allows them to avoid obstacles or people in their path, and can reload automatically if necessary. However, mobiles robots still cannot cope with a complex environment with the presence of humans. Human-aware robot navigation is challenging [5], [6]. Thus, the overall objective is achieved efficient, social and proactive human-robot collision-avoidance. Regarding the development of mobile robotic assistants that can help nurses and the elderly in their daily activities [7], we are interested in the situation where the user wants the robot to come to him. This type of robot must be able to perform tasks according to the current state of its environment, in order respond to the user's needs. Assistive robots can promote to reinforce people's autonomy in nursing home and help perform basic acts such as mobility, reminding people the of the weekly menu, reminding people the animation of places, etc. Today, many robots are able to move to the call, but this requires direct human intervention on the robot. In order to reduce the unnecessary number of trips, the principle of this project is to make the robot able to circulate autonomously to the point of emission of the call signal. In this article, the conception and construction of a system that allows a robot to move towards the call are detailed. In a first part, we will describe the localization technology used. In a second part, we justify our choice of the mobile robot used. Finally, we will present the results of the laboratory experiments. We consider the use of the Tiago robot already used in several interactional studies [8] [9].

II. LOCALIZATION TECHNOLOGY

Ultra Wide Band (UWB) [10] based on IEEE 802.15.4a standard [11] is a radio modulation technique that uses the transmission of very short duration pulses. Its high temporal resolution in the nanosecond range due to its wide bandwidth

compared to conventional narrowband systems. The width of the frequency band they occupy, generally in the range of 500 MHz to a few GHz. This high time resolution allows relatively accurate measurements of the signal propagation time between a transmitter and a receiver. It can also be used in close proximity to other RF signals without causing interference due to differences in signal types and spectrum. In addition, the UWB system is less sensitive to reflection, refraction or diffraction of waves in a multipath environment than narrowband systems, which reduces errors in propagation time calculations. UWB is very secure, the communication between Uwb signals is done with a unique random time code at a rate of several million bits/s, which makes them difficult to detect. Ultra Wide Band is more accurate than any other technology. Its precision and robustness ensure secure connections and prevent attacks on the system [12]. The determination of the UWB position consists of two steps: the calculation of the position and the estimation of the distance between the nodes. There are several algorithms for calculating the position [13], the system used in this project is based on trilateration.

A. Trilateration

The trilateration technique provide high telemetry performance to estimate the position of the mobile node by calculating the point of intersection between circles whose center represents the position of the node and whose radius is the distance between the fixed and mobile nodes [14]. The method uses the geometry of triangles to determine the position of the mobile node. It is a question of knowing the distance between the mobile and the various base nodes (figure 1).

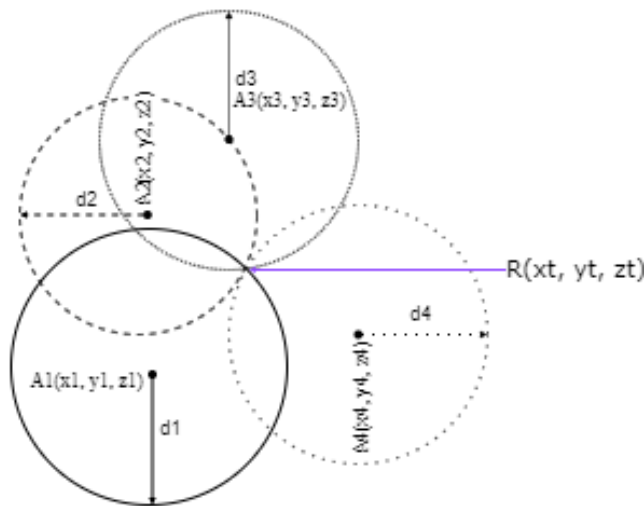


Figure 1: Localisation by trilateration

Let (x_i, y_i) be the coordinates of the transmitting stations and (x, y) those of the mobile that wants to locate itself. The position of each station and that of the mobile are linked by an equation (1):

$$d_i^2 = (x_i - x)^2 + (y_i - y)^2 \quad (1)$$

Where the values d_i are the distances between the mobile and each base station, which are deduced from the values. For a 2D location, the formula for spheres on a plane is presented in the following equations [15]:

$$\begin{cases} d_1^2 = (x_1 - x)^2 + (y_1 - y)^2 \\ d_2^2 = (x_2 - x)^2 + (y_2 - y)^2 \\ d_3^2 = (x_3 - x)^2 + (y_3 - y)^2 \\ d_4^2 = (x_4 - x)^2 + (y_4 - y)^2 \end{cases}$$

The position of the mobile node is obtained by calculating the following equation (2):

$$X = (A^T A)^{-1} A^T B \quad (2)$$

$$\text{With : } A = \begin{bmatrix} 2(x_1 - x_4) & 2(y_1 - y_4) \\ 2(x_2 - x_4) & 2(y_2 - y_4) \\ 2(x_3 - x_4) & 2(y_3 - y_4) \end{bmatrix}, \quad T = \begin{bmatrix} x \\ y \end{bmatrix}$$

$$B = \begin{bmatrix} (x_1^2 + y_1^2) - (x_4^2 + y_4^2) - (d_1^2 - d_4^2) \\ (x_2^2 + y_2^2) - (x_4^2 + y_4^2) - (d_2^2 - d_4^2) \\ (x_3^2 + y_3^2) - (x_4^2 + y_4^2) - (d_3^2 - d_4^2) \end{bmatrix}$$

B. Position determination

The Two Way Ranging (TWR) is used to find the position of the tag. The TWR protocol uses bi-directional communication between two UWB devices for 2d or 3D localisation. The actual distance between two nodes is obtained by calculating the time of flight of the UWB signal between the nodes, and multiplying this time by the speed of light divided by 2. To measure the distance, a message exchange is performed following the TWR protocol (figure 2):

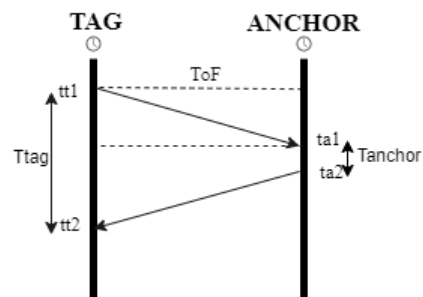


Figure 2: Two-way-ranging

The tag sends requests to the anchor at time t_{t1} , which estimates the reception time t_{a1} and sends returns a response at time t_{a2} . The tag receives the response at time t_{t2} and calculates the round trip time of the sequence.

$$ToF = \frac{T_{tag} - T_{anchor}}{2}$$

The accuracy of TWR depends on the accuracy of the anchor location and TWR does not need time synchronisation between its two nodes, it uses Time of Flight (ToF) [16] which is the travel time between the transmitter and receiver to measure the distance between them.

Once the ToF is acquired, we calculate the distance by multiplying the flight time and the speed of light:

$$\text{distance} = ToF \times (\text{Speed of light}) \quad (3)$$

III. ROBOTIC PLATFORM

The robotic platform is the set of hardware components used to implement software, it involves:

- The mobile robot: all the mechanical structure, actuators, battery, sensors, etc.
- The robot's location: Ultra Wide Band.

A. *Tiago Robot*

TIAGo (figure 3) is a service robot designed to operate in indoor environments. With this machine, it is the massive arrival of increasingly intelligent and versatile robots that will most transform, not to say disrupt, the lives of the elderly. Thanks to the combined progress of electronics, computer science and mechanics, a new generation of robots is now making its way into institutions for the elderly. TIAGo's features make it the ideal platform for social robotics research, especially for social navigation [17]. It is an autonomous robot that can move in human environments by projecting a trajectory that takes into account the human presence in the environment.



Figure 3: Tiago robot

The Tiago robot is equipped with various sensors: IMU sensors (gyroscope, accelerometer, and magnetometer), Lidar, and motor encoders:

- Laser Rangefinder Sensor: this sensor measures distances in a horizontal plane. It is essential for navigation and mapping.
- Sound sensors: These sensors measure short to medium distances. The sensor emits a sound signal and measures the reflection of this signal back to the sensor. They are generally used to avoid local collisions.
- Blocking the sensor or crossing several signals results in incorrect measurements.
- Inertial Measurement Unit (IMU): this sensor unit is mounted in the center of TIAGo and can be used to monitor inertial forces and provide attitude.

B. *Robot Localisation*

To send the robot to the call, the current position of the robot and the position of the remote control must be known. The difficulty of the problem is that the current position of the robot must be initialized. If the robot does not know its initial position, it will be very difficult to reach the goal, which leads to serious navigation errors.

Robot odometry estimates the position and orientation of the robot from wheel speed measurements alone. The Tf package is used to determine the position of the robot and manages the coordinates in a plane. The robot position estimate is saved in : `nav_msgs / Odometry`. The disadvantage of using the tf package in our project is that the positioning error increases with time and the long-term accuracy is low [18].

In order to provide efficient and more accurate indoor tracking, UWB and Lidar technologies are used. Light Detection and Ranging (LiDAR) is a remote sensing technology. It generally

has a laser pulse source and a receiver that accepts reflection. It uses multiple computational techniques to determine the distance between the source and the target [19]. The main advantage of LiDAR is that it can instantly measure distance and orientation in the environment. Therefore, the solution is to take measurements of the UWB trajectory to estimate the position of the robot, and calculate the orientation of the robot with respect to the map with LiDAR scans; then combine this information to initialise the position of the robot and use the estimated location as a reference point.

IV. EXPERIMENTAL RESULT

To find a solution to our problem, the problem was divided into three parts:

- (1) The location of the robot and its cartography which allow the robot to locate itself in its environment.
- (2) The location of the remote control that will be used to call the robot.
- (3) The navigation of the robot towards the remote control while avoiding obstacles.

The solution proposed for the first part consists in merging the data from the Lidar sensor and the UWB technology in order to know the initial position and orientation of the robot [20].

The aim of merging Lidar and UWB is to increase the accuracy of mapping and localisation. For the second part, we used UWB technology to detect the precise position of the remote control. And for the third part, the fusion between the laser scan and the RGBD scan of the robot allows obstacle avoidance and point-to-point navigation. In the proposed solutions, UWB technology is used for the robot and the remote control. For this, we need 4 anchors and 3 tags: 1 tag for the robot, 1 tag for the remote control and 1 tag connected to the computer that plays the role of the master. The first step is to install the anchors in the corners of the Lab room on posts at a height of 1.5m. The anchors are placed face to face vertically at least 20cm away from the metal so as not to degrade the performance of the system.

To find out whether the configuration was successful, we retrieved the list of devices, their identifiers and their coordinates in the system in turn. All components are well installed as shown in Figure 4 :

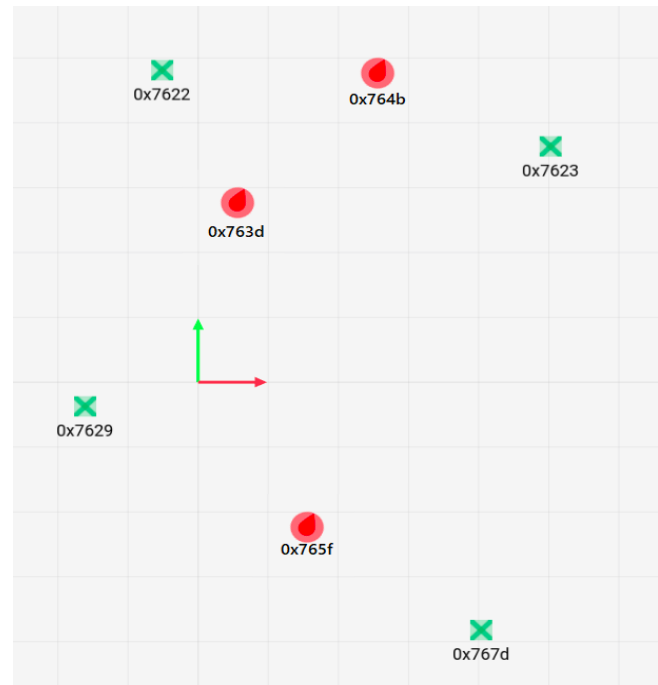


Figure 4: UWB positioning

Local Anchor with id 0x764b

Error : 0x00

Error Message : NO ERROR

Found Devices :

- 0x7623
- 0x7629
- 0x767d
- 0x7622
- 0x765f (Remote control)
- 0x763d (Robot)

The following diagram (figure 5) shows the solutions provided:

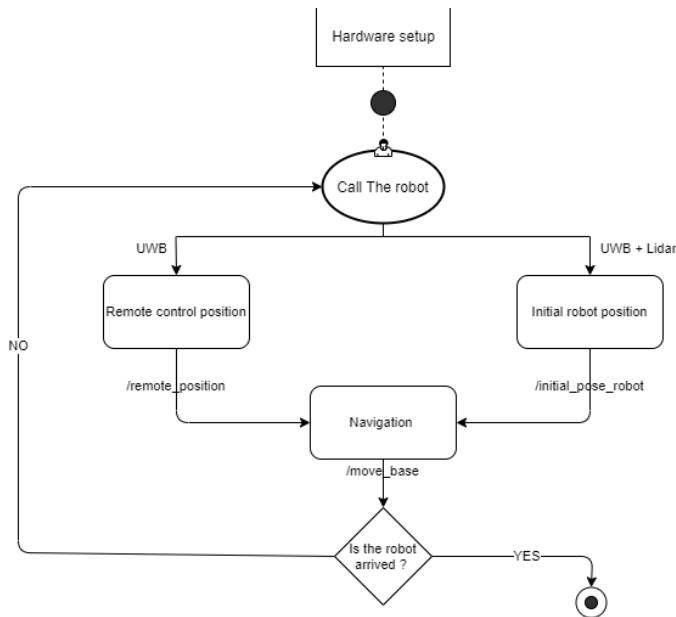


Figure 5 : Solutions script flow chart

A. TIAGO LOCALISATION

For autonomous navigation of the robot, we need to obtain the position of the robot before the move and define it as the initial position for the navigation. For this work, we use the open source operating system Ubuntu 18.04 on Debian Gnu/Linux and melodic ROS for ROS [21]. The ROS operating system is a framework used specifically for robotics. It is organised according to the structure shown in Figure 6.

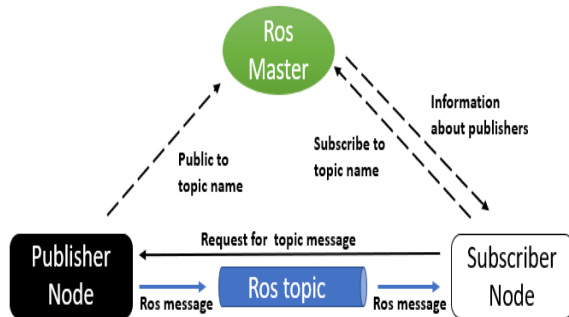


Figure 6: ROS structure

The initial position of the robot is calculated before the move by UWB, and the orientation is calculated by lidar. The combination of Lidar and UWB gives the initial position of the robot.

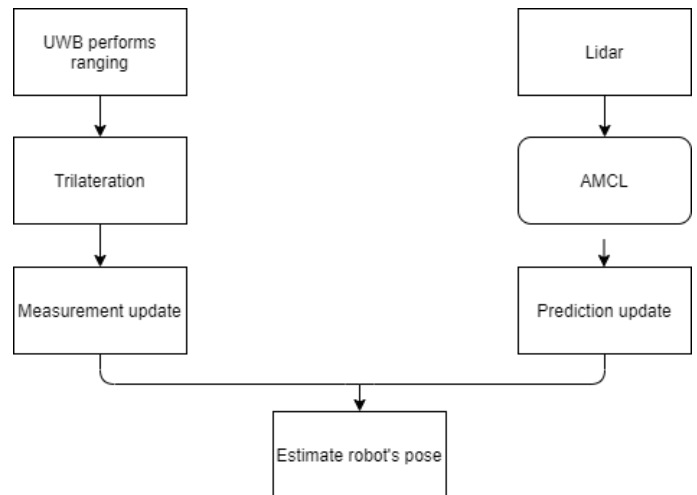


Figure 7 : Sensor fusion process diagram

We first use SLAM to map the environment of the room in which the robot is navigating. The lidar used for the Tiago robot is a 2D sensor with a 180° field of view and a range of 0.05 to 10 m. The lidar calculates the orientation of the robot. The orientation of the robot is calculated by the lidar. On a horizontal plane, the lidar sends a laser beam towards the obstacle, and calculates the distance to the obstacle by equation (3). For this reason, we need to extract the current position of the robot and define an initial position for navigation. The lidar continues to rotate up to 360° to obtain information about the environment and match it to the pre-generated map using adaptive Monte Carlo localisation (AMCL) [22].

```

1:  Algorithm MCL( $\mathcal{X}_{t-1}, u_t, z_t, m$ ):
2:     $\tilde{\mathcal{X}}_t = \mathcal{X}_t = \emptyset$ 
3:    for  $m = 1$  to  $M$  do
4:       $x_t^{[m]} = \text{sample\_motion\_model}(u_t, x_{t-1}^{[m]})$ 
5:       $w_t^{[m]} = \text{measurement\_model}(z_t, x_t^{[m]}, m)$ 
6:       $\tilde{\mathcal{X}}_t = \tilde{\mathcal{X}}_t + \langle x_t^{[m]}, w_t^{[m]} \rangle$ 
7:    endfor
8:    for  $m = 1$  to  $M$  do
9:      draw  $i$  with probability  $\propto w_t^{[i]}$ 
10:     add  $x_t^{[i]}$  to  $\mathcal{X}_t$ 
11:    endfor
12:    return  $\mathcal{X}_t$ 

```

The AMCL approach consists of locating the robot using particles. Each particle has its own coordinates, orientation and weight which is proportional to the probability. The AMCL algorithm is divided into two parts:

The first part consists of motion and sensor updating, while the second part is based on the resampling process. In the first part, a first initial position of the robot is given. Each particle represents a hypothesis of the robot position. When the Lidar sends a new measurement, the position of the robot is updated, and the weight of the particles is recalculated. In the second

part, the resampling process, the high weight particles survive and the low weight particles are removed. The high weight particles are then divided into several particles of equal weight. Finally, the particles give a better estimate of the robot's position. Therefore, the orientation of the robot is given by the laser scanner.

To calculate the position of the robot, we use the UWB sensor technology as explained in section (II B) for robot localisation. The tag 0x763d linked to the robot is used, and the anchors must be installed.

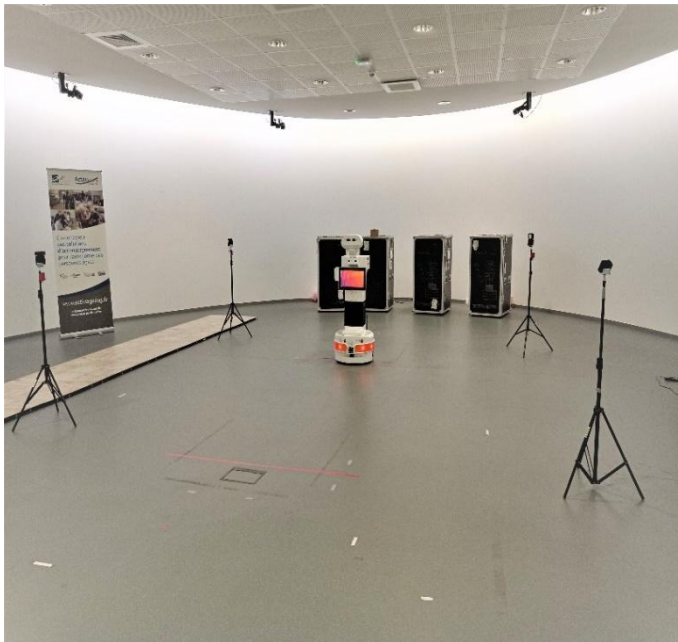


Figure 8: Test environment

We create a launch file where we note the coordinates of the 4 anchors, we define the tag used for the robot and we use a second tag that manages the information locally. We publish in a new topic `/uwb_data_tiago` the coordinate information (x_r , y_r , z_r) of the robot. Now that we have been able to retrieve the coordinates (uwb) and orientation (laser), we publish this information in the topic `/initial_pose_robot`

After these steps, the position and orientation of the robot are determined, and we define these coordinates as an initial position for the navigation of the robot to the call.

B. Remote control localisation

The remote control allows the user to call the robot with a single button. By touching the call button, we retrieve both the coordinates of the robot and the remote control, and send a

command to the robot to move towards the user it has called. In this project, we need to know in advance the location of the remote control, as well as being able to send the robot to the call. To detect the position of the remote control, we use UWB technology, which uses 4 anchors fixed in the test room, a beacon associated with the remote control and a master beacon connected to the computer. Following the protocol described above (II), the system calculates the position (x_t , y_t , z_t) of the remote control, which will be used as the robot goal.

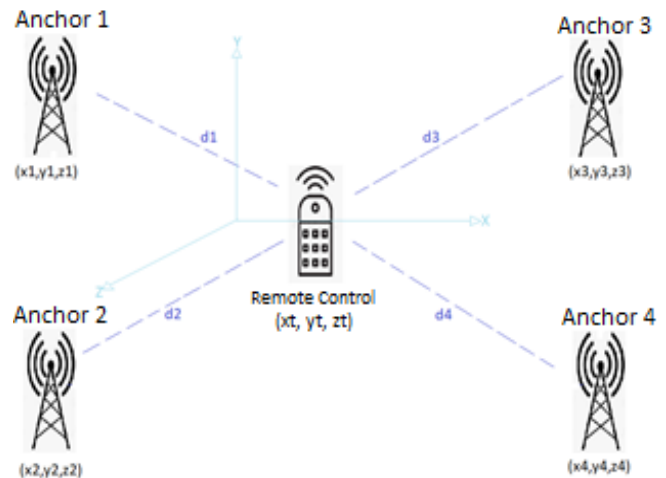


Figure 9: Calculating the position of the remote control

C. Obstacle detection

We are testing two obstacle avoidance systems. The first one uses only a laser Lidar and the second one uses a Lidar and an RGBD camera. For navigation and localisation of mobile laser robots, 2D LiDAR is a widely used sensor. However, one of the drawbacks of the first solution is that the robot only detects with a single horizontal scan line.

We take the example of the chair as an obstacle, we sent the robot to a point in front of the chair. The laser only detects the feet of the chair. After several tests, we notice that the robot hits the chair, and does not detect it (figure 10).

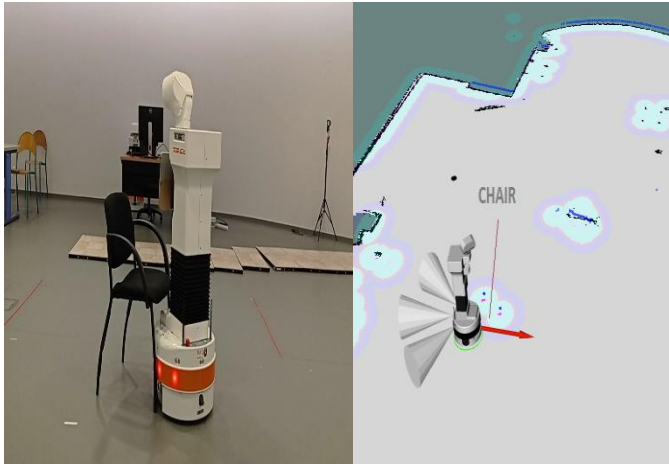


Figure 10 : Real test and simulation of laser for chair detection

We are trying the second solution which is to merge the laser and the RGB camera. When the robot moves, its head is lowered so that the camera's field of view generates the obstacles in front of it. This information from the camera is fed into the laser scan. The obstacle is then added to the map, and the robot looks for another path. We take the same example of the table, the robot navigates and detects the plane of the table via its camera, it stops and plans another path (figure 11).

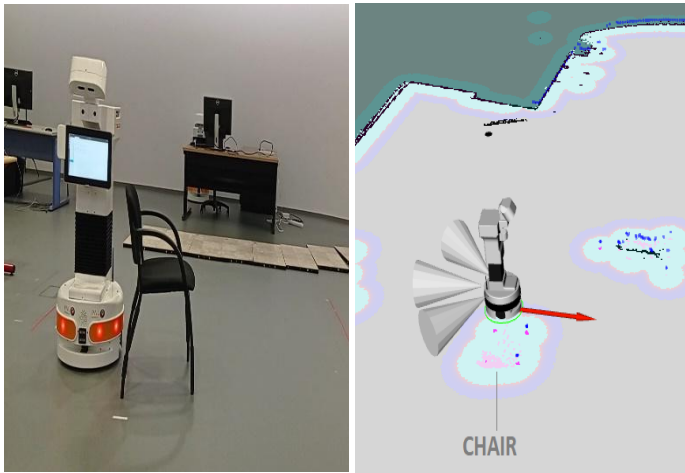


Figure 11 : Real test and simulation of the Lidar+RGBD for chair detection

The fusion of the Lidar and the camera allows a better detection of obstacles.

D. Results

The aim of the system is to help the user bring the robot to him without having to manually move it or constantly control its

navigation. For this purpose, we use a connected remote control that allows the user to call the robot with a single button.

The test of the call in the test room shows that the robot arrives at the call position with an accuracy of about 20 cm maximum and that it navigates in the room avoiding obstacles (Figure 12).

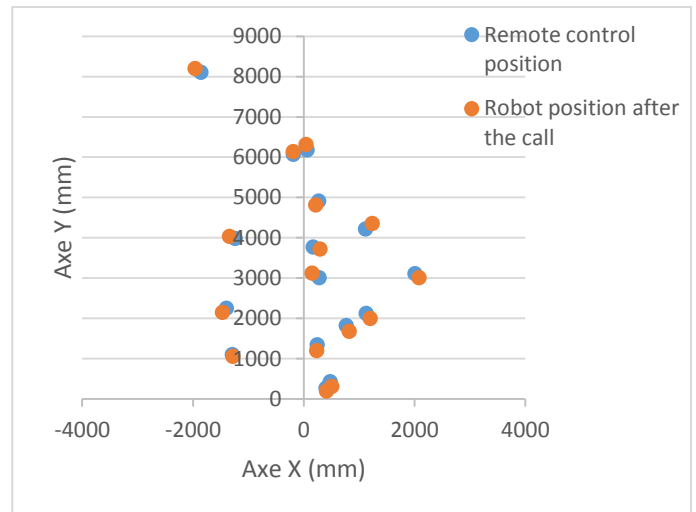


Figure 12 :System accuracy test

V. CONCLUSION AND PERSPECTIVES

We have developed a system to call the mobile robot using a radio remote control. UWB technology is used to detect the position of the remote control, and its fusion with LiDAR allows us to determine the position of the robot. Simulations and real tests have demonstrated that the robot arrives perfectly at the position of the call. We described a new feature aimed at making this mobile robot more useful to aging adults in healthcare institutions like rehabilitation centre or nursing homes.

With robot remote control, a simplified handset, we designed an added option in the mobile social robot for people. Caregivers members of can keep an eye on older patients in the common space, during which the patient to be more autonomous in order to achievement general information about their activities and the loved one has called out for discussions.

The next step in our research is to determine the optimal safety distance between the robot and the caller. In future work, solutions for enhancing human-robot interaction will be developed using a Living Lab approach.

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