Towards Low Cost Secured Remote Control of Mobile Robots to Help Dependent People

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***Abstract*—In this paper, we focus on a Web-controlled mobile robot for home monitoring, in the context of Ambient Assisted Living. The key point is low-cost and the robot is built from standard components. We use a few sensors to allow the robot to estimate its position, its direction and the obstacles in front of it. An Ultra Wide Band system is used to estimate the position of the robot. A distant user controls the robot by using a map in the user interface. The result is a small robot that can be used inside or outside a house.**

Keywords-Home monitoring; Web control; UWB positioning.

I. INTRODUCTION

This paper is an extension of [1]. In 1898, Nikola Tesla demonstrated a remote-controlled boat [2]. It was based on the radioconduction discovered by French physicist Edouard Branly in 1890. One century later, the emergence of Web technology provided new opportunities. The first Web controlled robot was developed at the University of Western Australia by Kenneth Taylor in 1995 [3]. At the beginning of the 2000's, Web development has led to the emergence of Service Robotics [4].

However, Web-controlled robots have rather remained unused until now, especially for Ambient Assisted Living (AAL) applications. A typical application consists of helping persons with diminishing mental or physical ability to stay at home as long as possible. When picking up the phone becomes too difficult, a mobile robot usable as a phone could be useful. In the same way, care helpers or relatives cannot spend all their time with a person. Devices that would be able to monitor what is going on in a house, to interact with the dependent person, and send the information to the care helpers could be of great interest. Cameras could be installed in every room. Such systems exist but they are not really acceptable because they are too intrusive. Thus, we think that a mobile robot could be more easily accepted [5]. The robot can look like an animal. It can move in the house, and only one camera is required in the house. If the camera is considered too intrusive, it can be replaced by a laser telemeter (Lidar) [6] to analyze movements in the house.

Such robots are easy to build at affordable cost. Some of them are even commercially available. However, there are still problems. The Romo example is typical [7]. The robot was launched in 2012 by the Romotive company. It is a mobile robot that uses a smartphone to control its motors. It can be remotely controlled from anywhere by using the smartphone connectivity. The cost is about €180. As soon as 2013, one Romotive co-founder wanted to move in the direction of making a robot that could solve real-world problems. After years of aimless decisions, Romotive's Website was shut down in 2016. Beyond disputes that have led Romotive to its fall, one key point appears. It is possible to build and sell toy robots. New telepresence robots such as UBBO or PADBOT are now available at affordable price (about €1000). The first one is an open source robot and the second one is a commercial robot. However, nobody knows whether it is possible to build and sell robots that can be used in the real world, especially in an AAL environment. In this part, we will ask why. We will review the main criteria required to make an AAL mobile robot truly usable.

A. *Security of the system*

If a software structure such as a server is installed on or near the robot, it can cause serious security problems in the house. It is never 100% secure. Even if techniques, such as traffic analysis are implemented, and if a problem is detected, who will handle the problem? It is not the role of the robot users.

If there is a wireless connection between a server and the robot, the radiations may cross the limit of the house and they can be captured and modified from the outside. Data will have to be encrypted but it may not be sufficient.

B. *Security of the persons and resilience*

If there is a failure, the robot may become dangerous. It may go anywhere in the house and hurt people. In any case, the speed of the robot must remain low. The robot should

not exceed 1 km/h to avoid frightening the inhabitants. The resilience of the system is also very important. The robot must be able to work despite total or partial failure of one or more components. For example, if the network performance decreases, the robot should automatically reduce its speed. When a fault is detected, the robot must be able to restart, and eventually go to a fallback position. An accurate positioning system must be available.

C. *Performance of the network*

When a command is sent to a robot through a network, if an acknowledgment is received back in less than 200 ms, there is no perceptible lag between the triggering of the action and the visual result [8]. A guaranteed 200 ms round-trip-time (RTT) allows secured remote command of mechanical devices. In the case of AAL robots, a 300-500 ms RTT remains acceptable if the speed of the robot is low (1 km/h). When the RTT is beyond 500 ms, the operator feels something uncertain.

D. *User interface*

The user interface must be designed for a semi-autonomous robot. When only using video feedback, controlling the robot is not easy. If images are not sent to the distant user for a while, the robot control may quickly get lost. The user interface must give accurate information about the robot, its position and its environment. The information must be redundant.

E. *Positioning*

Estimating the robot position is a key point. If the estimated position is not accurate, the whole system will collapse. The user interface will display wrong information, and the robot will be dangerous. Most of the previous criteria depend on the estimation of the robot position.

F. *The cost*

The cost must be kept as low as possible because it will probably be used by elderly people who often have tight budgets. It is inconceivable to rent a satellite channel to control the robot. In the same way, it is neither possible to use components, such as those found in military weapons, for example a €50000 inertial unit. From our point of view, the cost of an AAL robot should not exceed €500. The price of a TV or a high-tech smartphone is also a good estimate.

G. *Value analysis*

One important aspect of the robot is that the value is a combination of a remotely controllable mobility, with a panel of services, some supported by the robot itself, but mainly on-line services. Because of the rise of the latter, it is necessary to perform a continuous value analysis to increase the ratio services/cost, and to adopt the PDCA strategy.

H. *Sustainable robotics*

The domestic robots used to assist dependent people should be obviously sustainable. It is impossible to convince dependent people to reinvest for new robots at the same rate we reinvest for smart-phones or personal computers. The robots have to be reliable, robust, and highly maintainable. Probably the market will start when the robots will be rented as devices supporting specialized services, like intelligent personal assistants combined with authentic human contacts.

In this paper, Section II presents the proposed robotic system. We will show how the previous criteria have been taken into account. Section III presents the user interface. The results are shown in Section IV. The paper finishes by a conclusion and perspectives.

II. Designing a home robot for an AAL environment

A. *The mechanical base*

We use a very simple experimental mechanical base (Figure 1). There are four wheels mounted on gearmotors and a wooden plate. An Arduino and a motor shield control the motors two by two. The motor shield is a 2x2A. It is based on a L298P chip. This means that the robot will slide slightly on the floor when turning. This choice reduces the cost but it will make the robot more difficult to locate if odometry is used. The gearmotors rotate at a maximum of 84 revolutions per minute. The 120 mm wheels allow a maximum speed of 1.9 km/h. The motor torque is 0.1N.m. Thus, the total mass of the robot can be about 3 kg. This mechanical base is very reliable, especially if brushless motors are used.

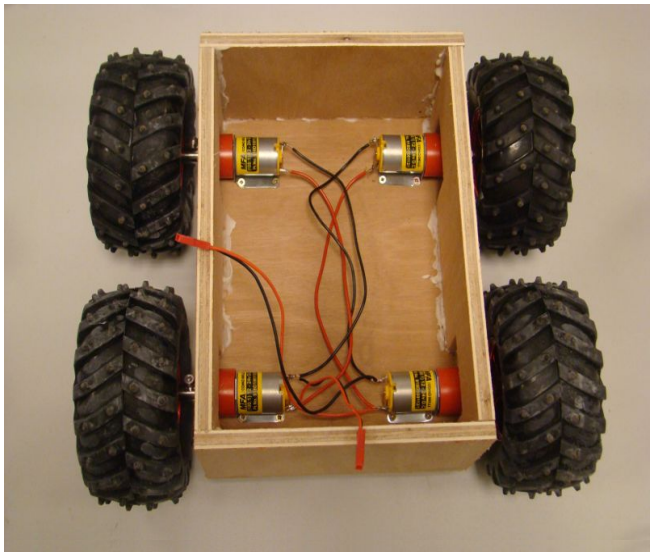

Figure 1. The mechanical base

B. The software architecture

If the mobile robot is in a house and the user in a different place, we have no choice but the Web to allow remote control. Another solution would increase the total cost too much. This leads to a special architecture that we describe below (Figure 2).

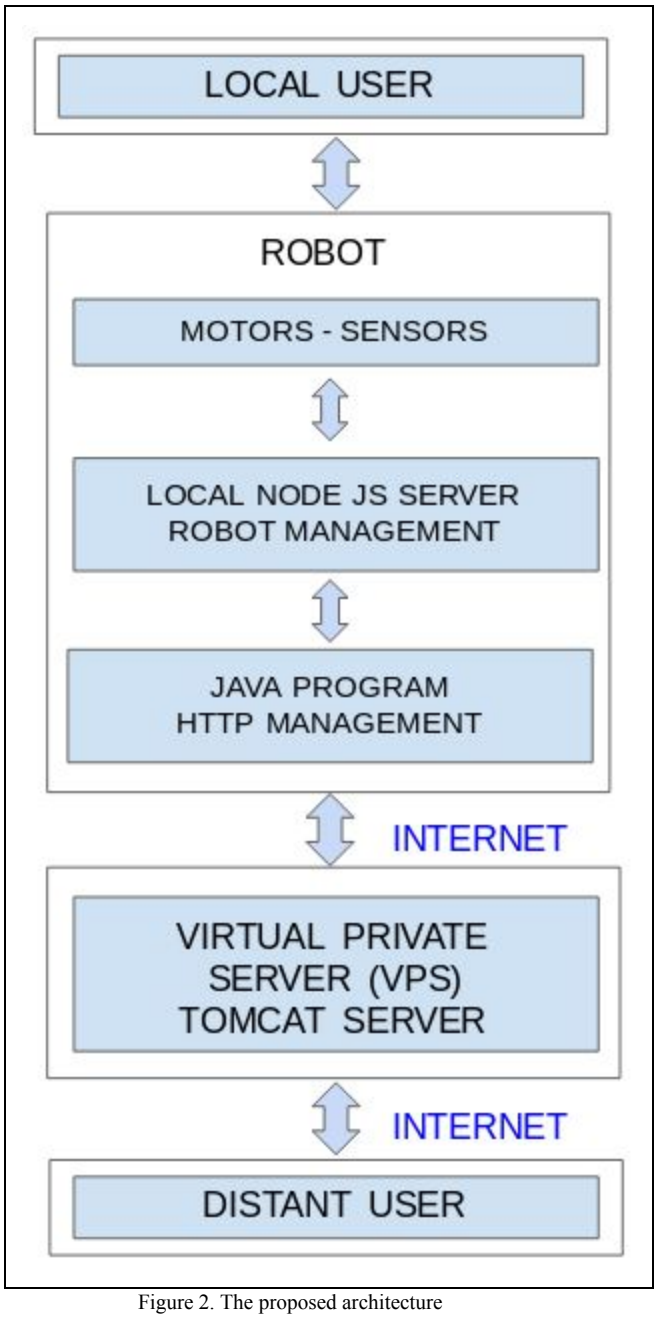

Figure 2. The proposed architecture

1) The Web server: The heart of the system is the Web server. We have chosen to use a Virtual Private Server (VPS) on the cloud. A 1-core VPS can now be rented at a reasonable cost of 3 or 4 euros per month. It is powerful enough to manage at one robot and one distant user. Of course, it can manage several distant users and several robots. For security reasons, it can be interesting to use one VPS to manage one robot and the users who use it.

The installation is relatively simple. A user interface is usually provided to install the system, for example an Ubuntu 16.04. The next step is software installation. It is nothing more that the installation of a Tomcat Web Server. That operation can be easily automated because there is only one archive file to copy and decompress. The installation of the application on the Tomcat server is also performed by copying a file. The copied file is automatically detected by the Tomcat server and installed as an application. Thus, installing thousands of VPS is possible at low cost.

2) The security of the Web server: The VPS provider monitors the network 24 hours a day. In case of problem, an email is sent and the VPS can be automatically rebooted, and even stopped in case of attack. If the server was installed at home, the monitoring would be less efficient. We can guess that the reaction time would be much higher in case of attack. Sophisticated algorithms are required to prevent an attack before it becomes a problem. Worst, a periodical ping to verify that the server is still alive, would be difficult to do at home. A second computer would be required to ping the first server. If installed at home, the second computer would also be vulnerable, and the solution to this problem has no end.

3) The distant user: There is no direct communication between the distant user and the robot. The distant user sends commands to the Tomcat server. Next, the Tomcat server sends commands to the robot. To perform such an operation, the distant user has a Web application running on a standard Web browser. Two solutions are possible to send the commands.

- The first solution uses Websockets. There is a first Websocket between the distant user and the Tomcat Web server, and second Websocket between the robot and Tomcat. Events sent on the Websockets are detected by Tomcat and copied from one Websocket to the other. Thus, when using a VPS located at 600 km from the robot, a complete round trip (user-tomcat-robot-tomcat-user) takes about 100 ms.
- The second solution consists of continuously sending HTTP requests. The distant user sends an HTTP request that is stored on the server. When the robot sends an HTTP request to the server, it receives a response containing the HTTP request sent by the distant user. In the same way, the distant user receives as response, the HTTP request sent by the robot. The synchronization is ensured by the server. When working at full speed, the robot sends an HTTP request and is let pending by the server until the distant user sends an HTTP

request. When the distant user has received its response, it sends a new HTTP request and is let pending by the server until the robot sends a new HTTP request. Thus, the server manages a standard producer-consumer system. In case of problem, a timeout is triggered and the process automatically restarts. The second solution is a bit slower. A complete round trip takes about 150 ms (user-tomcat-robot-tomcat-user). It has the advantage to be very simple and more flexible. There is no initialisation problem like with Websockets. Only asynchronous HTTP request are sent from the distant user and from the robot. The system can work forever with reliable automatic reinitialisation. There is no need for full speed at any time. The system can detect that the robot is not in use and can gradually decrease the number of HTTP request sent. For example, the robot can send one HTTP request every minute when it is not used. When the robot receives a command sent by the distant user, it can leave the standby mode and send up to several HTTP requests per second.

We have chosen this second solution because in our case, the state of the robot must be continuously sent to the distant user. Thus, continuously sending data on the Websocket, or continuously sending HTTP requests is not very different.

4) The robot: We have seen that the robot must send HTTP requests to the Tomcat server to get commands and send its state. A Java program running on a Raspberry will be used to do that. A second program runs on the robot. It is a Node JS server used to manage the motors and the sensors of the robot. The Java program sends HTTP requests to the Node JS server to make it move and get its state. The node JS server cannot be accessed from the outside for security reasons. The Node JS server has been chosen for its ability to manage asynchronous events and easily capture information from the sensors.

The electronics on the robot is managed by a set of Arduinos. All the information goes through a master Arduino connected to the Node JS server. The master Arduino is connected to a set of Arduinos (Figure 3). All the communications, including that of the master Arduino to the Node JS server, are at the rate of 9600 bauds. Such a speed brings reliability and is fast enough for our purpose. The speed can be very low because information coming from the sensors can be stored in one or two bytes. For example, it takes about 1 ms to get a distance produced by a Lidar. Sending the whole state of the robot to the Node JS will take less than 10 ms when the position of the robot and the distance to obstacles are taken into account.

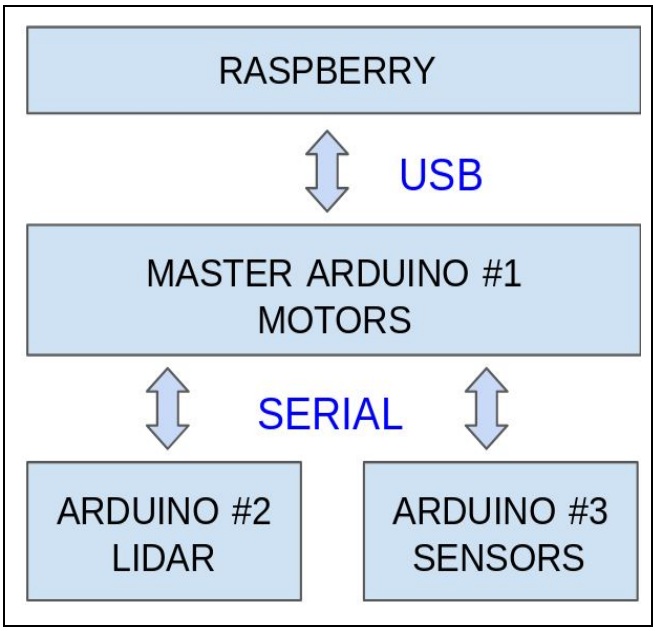

Figure 3. The Raspberry and the Arduinos

5) Complete stop of the robot: Another element of security is the complete power off of the robot when not used. The distant user can switch the power off or on the robot. We have a special charging dock for that. There is an Arduino on the robot, different from those seen above. It is completely independent and not powered when the robot is used. It manages relays, in fact inverters. When the Arduino is not powered, relays are in a mode such that the robot is powered. When the robot comes to the charging dock, a connector powers the Arduino. When powered, the Arduino reverses the relays and the robot is powered off. The connector that powers the Arduino can be controlled by the distant user. Thus, the distant user can power the robot on or off. The control of the connector is similar to that of the robot. A second Raspberry working like that of the robot is used. The only difference is that the second Raspberry is programmed to send HTTP requests to the Tomcat server at a low rate of one per minute. We also use batteries with embedded charger. By just adding another connector on the docking base, charging of the batteries can be triggered, either automatically and periodically by the system, or manually by the distant user. We just send power to the charging devices of the batteries by using relays. When the battery is fully charged, the charging device automatically switches the charging off. The battery life time is increased because both the robot and the charging device are powered off. Intrusion also becomes more difficult on the robot. The system is designed to be used by a small number of users. When the robot is powered on, an email is sent to the users and a confirmation can be expected from one of them. In this way, the users will be able to easily detect eventual intrusions.

6) The client side: The remaining question is the software on the user side. We have chosen a thin client for security reasons. A fat client would have been more powerful but the risk of security breach would have been higher. When using a thin client, we use a standard Web browser and rely on its security. The Web browser communicates with a Tomcat Web server that is fairly secure. The HTTP protocol is used.

C. The sensors

A distant user could make the robot move by using basics commands, such as forward, backward, right or left. If video is available, remote control is possible.

A webcam is available on the robot. It is managed by a Raspberry. It is a light solution to stream videos over an IP-based network. The webcam is independent from the robot. The Tomcat Web server catches the video and sends it to the distant user when required. Thus, the webcam is not directly accessible from the outside. Only the Tomcat Web server can be accessed from the outside and security is kept relatively high because distant users must be identified in order to get the video images.

However, if the mobile robot is used by caregivers who do not know the house very well, video feedback is not sufficient because experience shows that users are quickly lost. Moreover, estimation of the position of obstacles is not easy with video only. Thus, we have two main problems: estimating the obstacle positions, and estimating the robot position in the house.

Estimating the obstacle positions can be done by using a laser telemeter (Lidar) [6]. Such devices are available since several years. However their price can easily reach €2000. We rather use a €150 Lidar-lite that can measure distances in only one direction. To scan a 180 degree field in front of the robot, we have mounted the Lidar-lite on a servo motor.

To make the robot go forward and follow a direction, we also use a 9-axis accelerometer/magnetometer. Experiments have shown that for our problem, a Kalman filter is required. Without the Kalman filter, the magnetometer produces many wrong values. Using an extended Kalman filter does not seem to be necessary until now. We use a €30 CMPS11 tilt compensated compass module from Robot-Electronics [9]. The module includes a processor to compute a Kalman filter. It processes the raw values produced by the gyroscope, the accelerometer and the magnetometer. The compass output is pitch, roll and heading. To give correct results, the compass must be at 30 cm above the gear motors. Only heading will be used in our case. We will use that value to make the robot follow a direction. The distance traveled by the robot could also be computed from the accelerometer data, but the errors would accumulate and the position of the robot would be incertain. We will rather use UWB to determine the distance traveled by the robot.

D. Estimating the robot position

Estimating the absolute robot position is now possible, thanks to UWB. One of the main features of UWB signals is their potential for accurate position location and ranging. UWB technologies are often described as the next generation of real time location positioning systems. Due to their fine time resolution, UWB receivers are able to accurately estimate the time of arrival (ToA) of a transmitted UWB signal. This implies that the distance between an UWB transmitter and an UWB receiver can be precisely determined.

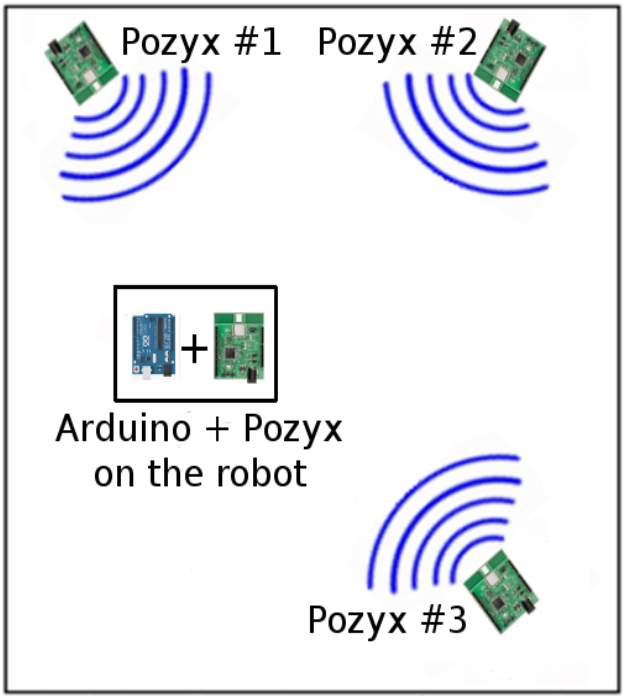

Figure 4. The positioning system

This feature of high localization accuracy makes the UWB an attractive technology for diverse ranging and indoor localization applications. It really allows 10-30 cm accuracy in ranging and promises the realization of low-power and low-cost communication systems [10].

The Arduino on the robot is connected to a Pozyx [11]. It computes the distance from the robot to the three other Pozyxs (Figure 4). When the signal received from the reference nodes is noisy, the system is non-linear and cannot be solved. An estimation method has to be used. To get a satisfying approximated position of the mobile robot, we use the Newton-Raphson method [12]. This method attempts to find a solution in the non-linear least squares sense. The main idea of the Newton-Raphson algorithm is to use multiple iterations to find a final position based on an initial guess (for example, the center of the room), that would fit into a specific margin of error.

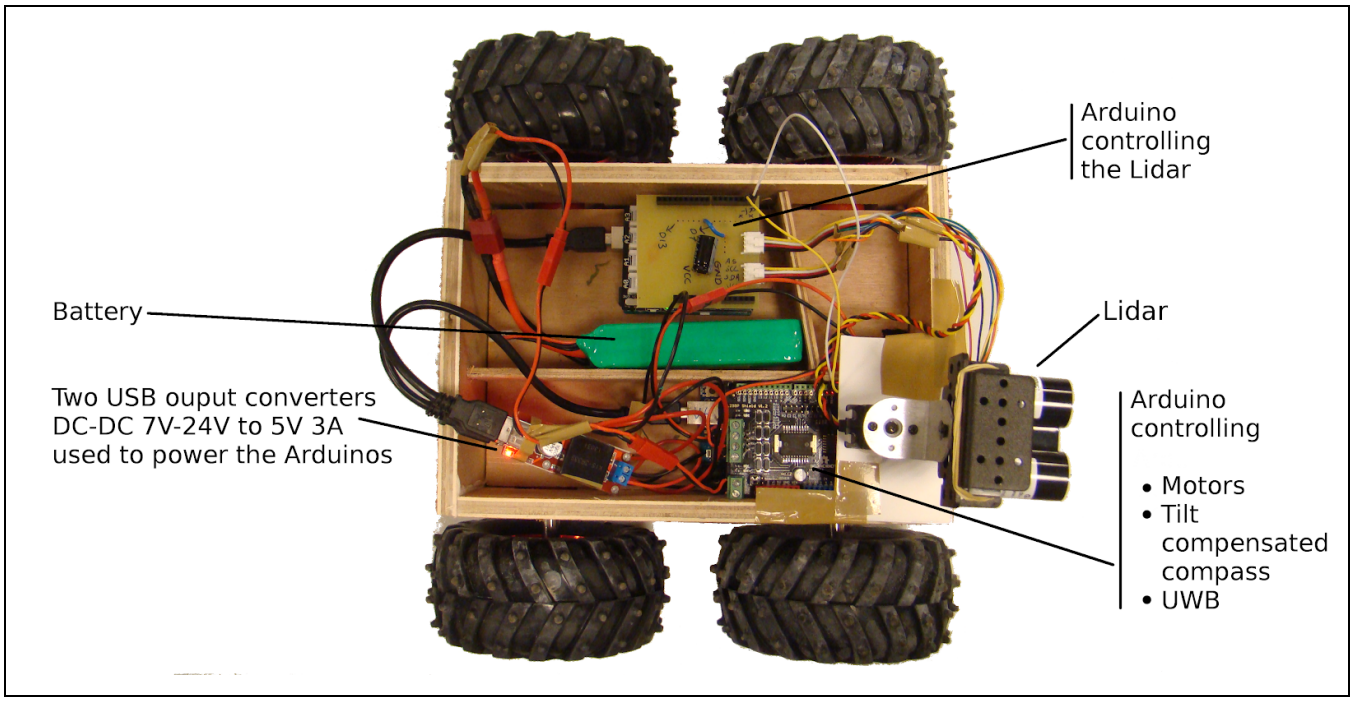

Figure 5. A part of the robot (compass and webcam not shown)

The first results of our experiments show that distance values are not consistent due to multipath components. Hence, the precision of our system is about 30-50 centimeters. Such a precision is sufficient to know where the robot is in a room, but insufficient to pass through a door or a narrow passageway.

After the addition of sensors and UWB positioning, the mobile robot architecture is as follows. The robot includes several sensors that are managed by two Arduinos communicating through a 9600 baud serial link. The first Arduino manages the motors, the Lidar-lite laser telemeter, and the compass. It is able to make the robot move, stop if there is an obstacle, and follow a direction. It communicates with a second Arduino that estimates the robot position. The second Arduino periodically sends the estimated position to the first one. It can also send orders, such as stop, change the heading, or move forward in the current direction over a certain distance. To estimate its position, the second Arduino computes the distance between itself and the Pozyx modules. To compute the position, the Arduino sends the measured distances to the distant computer that processes the Newton-Raphson algorithm. Results are obtained faster if the computer has efficient floating point capabilities.

A part of the obtained robot is shown in Figure 5. A single LiPo 3s battery powers the robot. DC-DC converters are used to power the two Arduinos.

The robot is now able to estimate its position by using UWB Pozyxs. It is also able to communicate with a remote server installed in the house, to detect obstacles by using a Lidar-lite, and to follow a direction by using a compass. We must now propose a user interface to make all those features available to a distant user.

III. THE USER INTERFACE

A. *Using a map*

The main item of the user interface is a map. We show the robot moving on the map in real time. To build the map, we have chosen to extend an available solution: OpenStreetMap [13]. In France, most of the buildings, including the individual houses, are shown by OpenStreetMap. Thus, we can use these basics plans that show the edges of the buildings. We superimpose a detailed plan on the basic OpenStreetMap plan. To build the detailed plan, we provide a tool that allows to draw on the basic OpenStreeMap. It is implemented by using the OpenLayers V3 (or V4) standard library [14]. Details such as furniture or door openings can be shown. The direction of the exterior walls relative to magnetic north is shown by OpenStreetMap, and all other elements can be placed on the map accordingly (Figure 6). More sophisticated solutions, such as Lidar analysis have not been experimented yet to automatically produce maps. Although limited, the current solution is easy to use and makes it easy to produce a relatively detailed plan.

When zoomed in, a room of a house can be seen in full screen. The robot position is shown by the letter “R”. The direction of the robot is shown by the direction of the letter.

For example, if the letter is inverted on the map, the robot goes south.

To make positioning work, we must hang three Pozyxs on the walls. Our algorithm requires that they must be at the same height which can be different from that of the robot. In order to simplify configuration, the three Pozyxs must form a right angled triangle (Figure 7). Thus, in the user interface, there is something to indicate the position of the #1 Pozyx (P1), the position of the #2 Pozyx (P2), the distance between the #1 and #2 Pozyx (P1-P2), and the distance between #1 and #3 (P1-P3). The system deduces the position of the Pozyx #3 and there is no need to indicate directly its position. Pozyx configuration is very easy because walls of a house are very often perpendicular. The distant user must click twice on the map, the first click to indicate where the #1 Pozyx will be positioned, the second one to indicate where the #2 Pozyx will be positioned. Using a perpendicular axis for the Newton-Raphson algorithm we use in position estimation, can lead to problems because divisions by zero can occur. In fact, experiments have shown that it is not a problem. If one position estimation can not be computed, the next one almost always can be computed. Even if the robot is stopped, the Pozyxs continuously produce distance values.

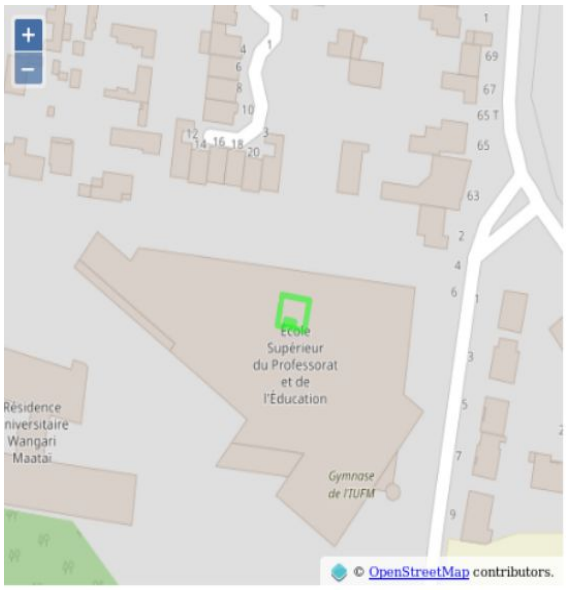

Figure 6. Example of OpenStreetMap plan with overlay

As soon as the Pozyxs are configured in the user interface, the robot position is displayed. The user interface shows the estimated distances between the robot and the Pozyxs by means of three circles. Those circles were used for debug at the beginning. We keep them in the user interface because they show a living system. The circles oscillate slightly continuously and the distant user can see if the system is working or not, and if there is no network problem. As seen above, the robot position is shown by the letter "R". It should be at the intersection of the three circles.

The implementation has been done by using Javascript [15], Ajax [16], jQuery[17] and OpenLayers V3 [14]. An Ajax request is sent to the Tomcat Web server, the position is computed as seen above, and the result is sent back to the distant user, and shown on the user interface. As soon as the result is available, another Ajax request is sent and another position estimation expected. We have measured a round trip time (RTT) close to 500 ms when the distant user is in the same town as the robot. It takes about 100 ms to compute a distance from one Pozyx to another. As there are three distances to compute, we have a 300 ms duration. The results must furthermore be sent to the Tomcat Web server, and we have a RTT close to 500 ms to communicate between the distant user and the robot.

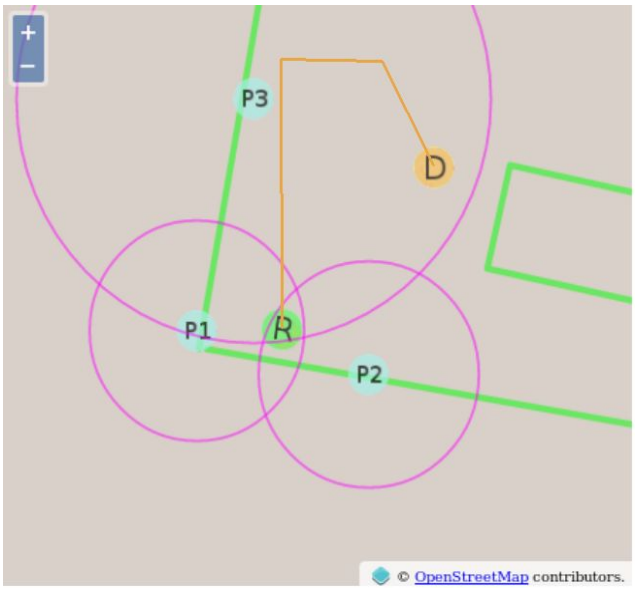

Figure 7. The user interface map

The RTT is also used on the robot. When the RTT increases, the robot automatically reduces its speed, or stops, or goes to a fallback position. Thus, if the robot does not receive commands from the Tomcat Web server, it stops.

B. Making the robot move

To make the robot move, the distant user must indicate a destination position on the map by clicking once or more. In Figure 7, there is an orange stroke that can be split into three segments. To draw such a stroke, the distant user must click three times. The last click corresponds to the desired robot destination.

Figure 8. Elements of the user interface

To make the robot reach that destination, the user interface will automatically send a set of commands to the robot. The three segments will be processed one by one, as follows:

- Computation of the direction of the segment (almost north for the first segment in Figure 7)
- Alignment of the robot in that direction
- Computation of the segment length
- Sending a command to the robot to make it move by the desired distance in the current direction
- Stopping the robot for two seconds to have a better robot position estimation
- Verification of the current position of the robot and adjustment (adjustment can be automatic or performed by the distant user)

We finally obtain a system that allows semi-automatic robot remote control. In addition to the map, the distant user has a control panel to monitor the robot (Figure 8).

The current user interface is experimental. It shows the distances measured from the Pozyxs (P1R, P2R, and P3R), the Round Trip Time (417 ms in Figure 8), the position of the robot on the orthogonal axis defined by P1, P2 and P3 (1.32 m from P1 on the X-axis defined by P1-P2, 0.29 m from P1 on the Y-axis defined by P1-P3).

The user interface also shows the heading of the robot in degrees (8 degrees, almost north, in Figure 8), and also the unused pitch and roll values. The distance from the closest obstacle to the robot is also shown (0.97 m in Figure 8). There is also a set of buttons to define a new robot destination and make the robot move.

In the next section, we will show the results and review the criteria exposed in the introduction.

IV. Results

A. *The total cost*

In the introduction, we said that the total cost should not exceed €500. The mechanical base costs about €100, the Lidar-lite about €150 [18], the compass about €30 [9], and the webcam about €100 including Raspberry PI 2 (Figure 9). We reach a maximum €500 total cost, Pozyx excluded.

One Pozyx is about €150 [11] and we need at least five. However, we think that it is not a problem. The very first Pozyxs were sold by the end of 2015 and the price will probably fall. The Decawave DW1000 chip used on the Pozyx module costs about one euro. The DWM1000 version that includes an antenna is now sold per unit for €30. We can expect UWB boards to be much cheaper in the near future. If a €50 UWB board was available, the cost criteria would be almost met. In fact that already exists.

Figure 9. The experimental robot

B. *Performance of the external network*

We have been testing Web performance for a decade. Tests have been done from Brest (France) to Auckland (New-Zealand). It is the longest distance possible in the world. Results are shown in Figure 10.

The top diagram shows the measures taken in 2005 overs two weeks (horizontal axis in Figure 10). We have measured the Round Trip Time (RTT) between two computers, one located at the University of Brest (France) the other at the University of Auckland (NZ). We have obtained values from 495 to 1093 ms (vertical axis in top diagram in Figure 10). The average RTT is 768 ms. Exactly ten years later, the average RTT is 415 ms and most values are close to this average (bottom diagram in Figure 10). The minimum was 295 ms. The measures were performed between one Wi-Fi connected computer, located in a hotel in Auckland (NZ), and another computer located at the University of Brest (France).

This means that the Web can be used for remote control all over the world. However, we still have numerous RTT values greater than 500 ms. A RTT prediction system would be of great interest.

In fact, the problem comes from the UWB devices. The positioning process is very slow because communication between a Pozyx and an Arduino UNO is slow. One reason seems to be the use of the I2C Arduino bus. The Decawave chip on the Pozyx board uses the SPI bus (Serial Peripheral Interface Bus). The SPI bus must be converted to an I2C bus. Faster Arduinos or equivalent could improve communications. Direct connections to the Decawave chip by using the SPI bus could also produce improvements. That remains to be tested.

C. *Security of the system*

The security of the system is that of a distant user communicating with a remote Tomcat Web server through the encrypted HTTP protocol.

D. *Security of the persons and resilience*

The robot is able to detect any problem on the network and stop if required. Its low speed should make it safe for people. Experiments have shown the positioning system is accurate in the range between 30 and 50 cm. Perfect positioning is not available but it seems sufficient in a current AAL environment. The main remaining problem is door crossing. A better use of the Lidar could be the solution.

E. *User interface*

On the user interface, we can follow the robot on a map. As first experiments have shown that the Pozyx positioning system seems to be reliable, we have a control system based on standard components, such as OpenStreetMap. The time required to configure the system and make it work is very short.

F. *Positioning*

Even if the 30-50 cm obtained precision does not allow to make the robot go everywhere in house, it allows the robot to follow predefined paths. These paths must only be carefully chosen because the Pozyx signal may be easily

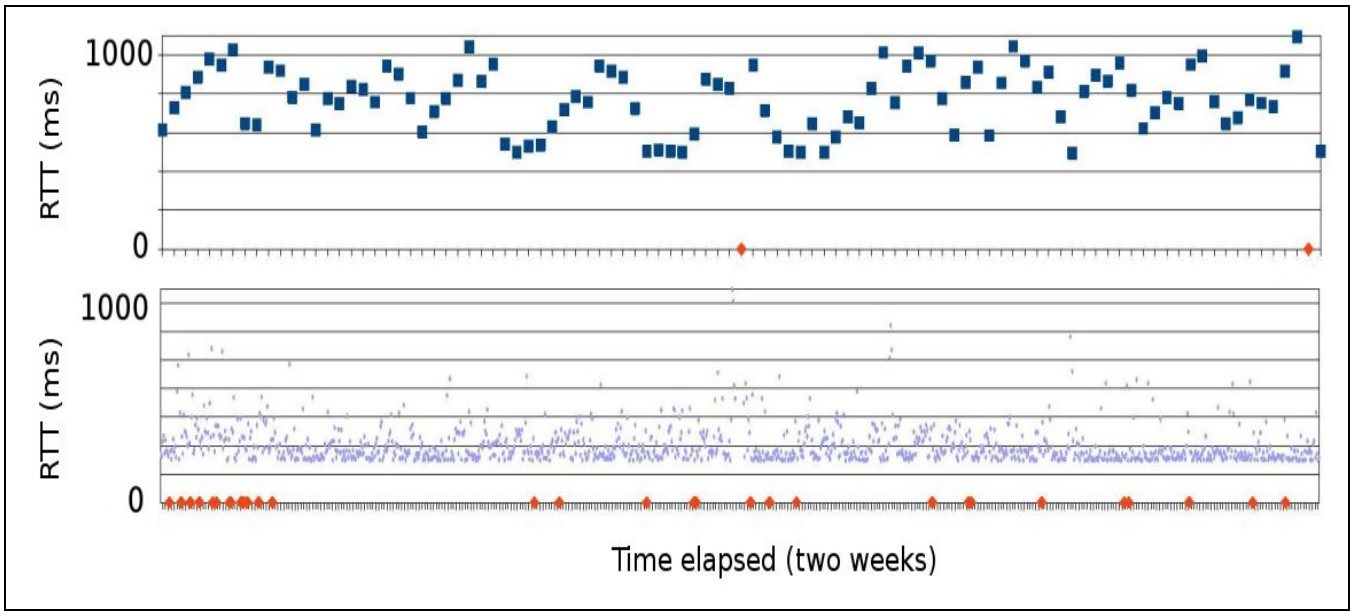

Figure 10. Web performance 2005-2015

stopped. The signal is very weak (about -40 dBm) and has shown to be very sensitive to metal obstacles, even if they are small.

V. Conclusion

The aim of this paper was to present a mobile home robot that could be helpful for old and/or dependent persons, and easily used by caregivers or relatives. Proposing a low cost solution, using high tech components, promoting simplicity were some of the key ideas that conducted this project.

This has been achieved by the use of a positioning system based on UWB Pozyx modules. Combined to a map in the user interface, it seems to be a promising technique.

However, the cost of the UWB components remains high, and the inaccuracy significantly exceeds 1 or 2cm. Even if the cost of an UWB component is now less than €20, it can be estimated that at least four UWB components will be required in each room. A better use of the Lidar, combined with a small number of UWB components, should be experimented to decrease the cost, and increase the ease of installation.

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