POSITIONING WITH ULTRA SONIC SENSORS : REVIEW OF TECHNIQUES AND PRESENTATION OF A NEW SYSTEM

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ABSTRACT

Ultra-sonic sensors are very popular in laboratories carrying out work about mobile robot. This good reputation comes from attractive low prices of sensors and from a rather simple implementation. CSTB also used this technique to position the SOFFITO robot (first experimental mobile robot for building construction sites in Europe developed jointly with IIRIAM and AID). From this experience, we concluded to the necessity of improving the positioning system which consisted of a belt of 24 ultra sonic sensors and required a particular coating of partition walls to work in good conditions. After reviewing the uses of ultra sonic sensors for metric positioning system, we developed a particular system consisting on two sensors mounted ion two rotating vertical axises. The aim of such a system is to ensure distance measurement to the walls, when the ultra-sonic beams are normal to the walls. From the measurements of two distances and of the angles of the sensors relatively to the mobile, the position is known. This paper presents a review of previously developed systems and gives details about the design of the new system.

KEY WORDS

Mobile robot, positioning system, sensors, ultra-sound, building, construction

1. Generality

The principle of ultra-sonic detection is based on the measurement of the time of flight (TOF) between the emission and the reception of a ultra-sound wave (typically between 40 kHz and 200 kHz frequency).

An ultra-sonic sensors system includes both a transmitter and a receiver. TOF is measured from the first one to the second one (fig.1a). These two parts are frequently gathered in a single box. In this case, distances are measured through TOF with echo on a reflecting surface (fig. 1b). This second method is often used for robot positioning, using the walls as reflectors, and for obstacle detection.

Ultra-sonic sensors are rather cheap and have reasonable accuracy between 30 centimeters and few meters. The angular opening is about 20 degrees.

Most troubles for accurate positioning are caused by approximated distances evaluation when echo is not good enough.

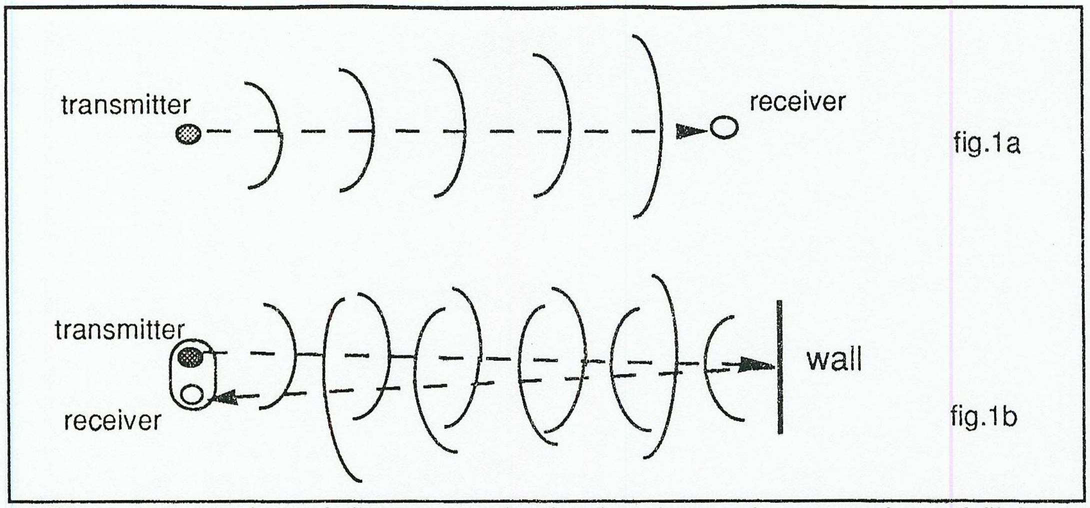

Figure 1 : principle of distance evaluation by ultra-sonic waves time of flight

2. Uses of ultra-sonic positioning systems

2.1 Review of ultra-sonic uses

Many solutions have been tested and/or implemented on mobile robots using ultra-sonic devices for both positioning and obstacle detection.
They can be classified among two main classes, whether they use external sensors in the surroundings or only on-board sensors.
In the first class, we can think either of on-board transmitter and receivers placed in the moving area or the opposite.

A system using passive sensors on the vehicle is described in [1]. It is based on a set of transmitters placed in the environment of the mobile robot. The positions of these beacons are known. Omni-directional receiver are fixed on the vehicle. The transmitting beacons emit ultra-sound signals periodically and at a regular rate, in order to be distinguished from each other. As several beacons are necessary for the vehicle positioning, a great attention has to be paid to the initial setting of time interval between two beacon signals. When receiving signals from three different beacons, and after computation of the corresponding distance, the mobile robot can be located (fig. 2).

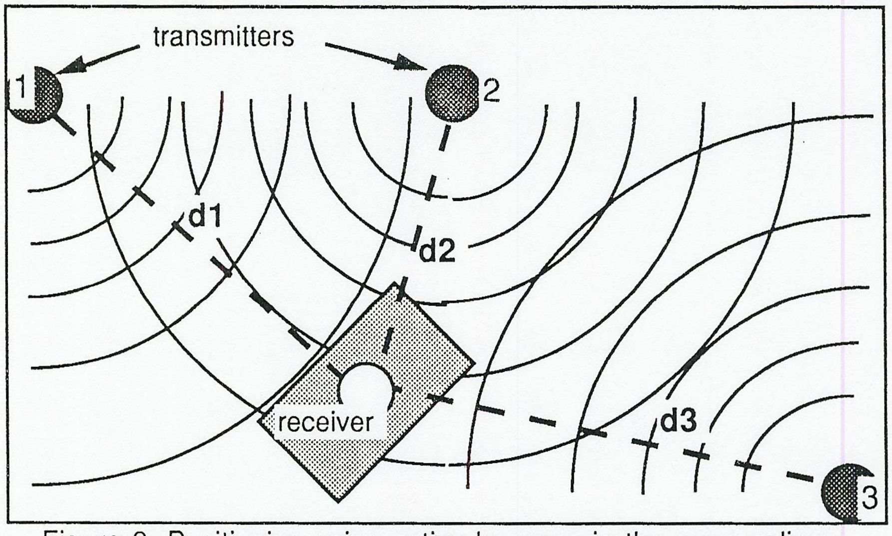

Figure 2. Positioning using active beacons in the surroundings.

A similar system to be mentioned was used in the RADIOUS project [2]. In this case, transmitter are set on the vehicle and several receivers are placed in the surrounding. Each receiver provides a distance measurement which is sent back to the robot through radio transmission.

Another ultra-sonic positioning system [3] consists of a central transmitter and two lateral receivers. This sytem derives from bats echolocation principle and allows to measure both a distance and an angle from TOF difference. The emitted signal comes back after echo to the two lateral receivers with a delay which is directly related to the incident angle (fig. 3).

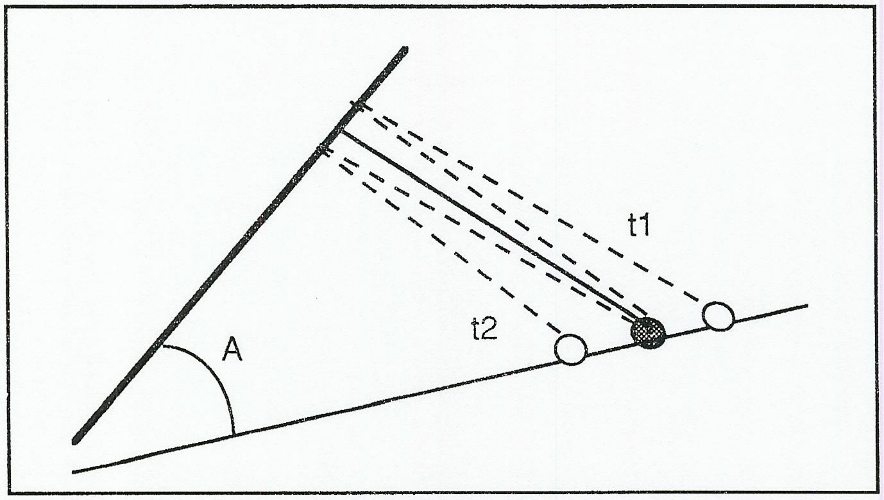

Figure 3. Angle and distance measurements using ultra-sonic sensors.

The most common system consists of a large set of sonar sensors placed all around the vehicle [4], [5], [6]. Each of these sensors scans the environment of the mobile surrounding in one direction. They are transmitter-receivers and so get a distance measurement by TOF evaluation with echo. The transmitters are either continuously active or only upon request from the navigation system. Through this system, the vehicle gets an image of the surrounding room. The position can be reached by matching this pattern with an a-priori knowledge of the real room (fig. 4).

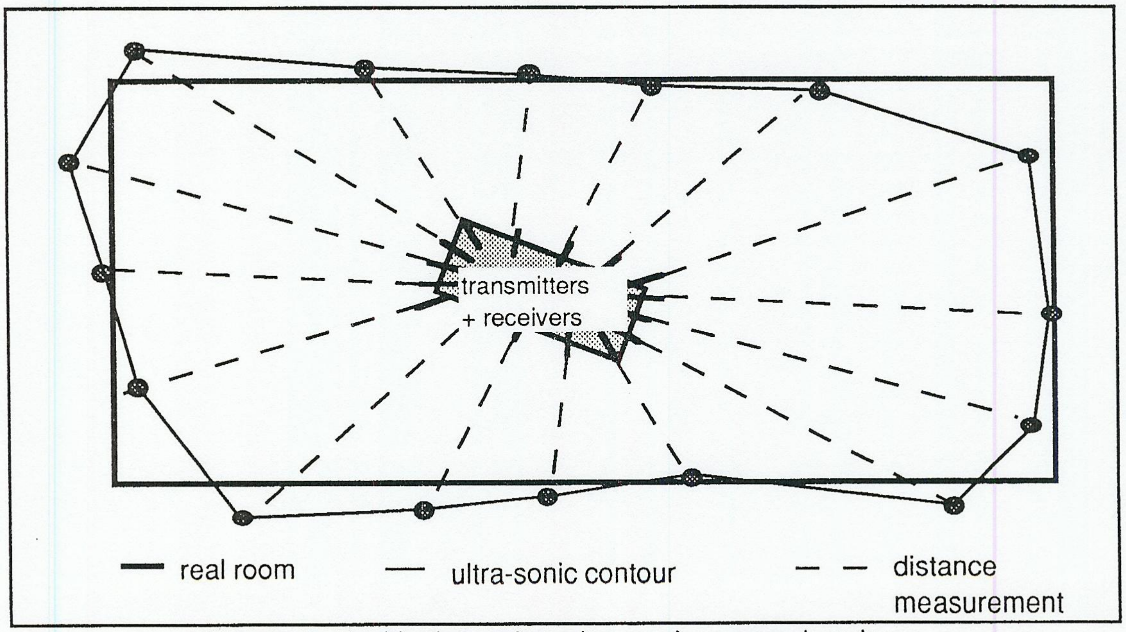

Figure 4. Positioning using ultra-sonic sensor bandeau.

Such a system was used in the 'SOFFITO' experimental mobile robot. Provided that good echo can be obtained, this positioning system is accurate enough for indor mobile robot.

2.2 The SOFFITO experiment

From 1986 to 1988 the CSTB led a research program named SOFFITO [6] in which two other french partners were involved - a research center in computer sciences IIRIAM, and a manufacturing company AID -.

The aim of this project was to develop an experimental mobile robot for building construction tasks.

As far as possible, commercialy available standard sub-devices were used.

The chosen task was the painting of ceiling, and a vehicle was designed (figure 4) to load the painting robot arm and all the necessary control systems - tools control, motion control and positioning -.

The positioning system consisted of a belt of twenty-four ultra-sonic sensors set all around the vehicle.

The navigation software was derived from CROWLEY's work [7] and the ultra-sonic system (including sensors, CPU and interfaces board) was purchased from the ROBOSOFT company.

The conclusion of this experiment was that both the ultra-sonic system and the software were good tools but with no future for our applications.

The walls of the test cell of the SOFFITO robot were made of plaster boards which are very widespread in building construction (partition walls, inner part of masonry walls).

Due to reflection properties of the plaster boards, it was not possible with standard boards to get echos of the ultra-sound waves from all of the twenty-four sensors.

To get such an echo, and then a correct image of the surrounding walls, we were obliged to cover the plaster boards with a rough coating.

With such a wall surface, the SOFFITO robot was very successful when executing indoor work. But such a modification of the environment is of course unacceptable for building construction applications.

From this first experiment we were pushed to imagine more suitable solutions.

2.3 Synthesis

None of the previous systems could be widely used on mobile robot for building construction tasks.

Two main features of these systems are essential drawbacks for our applications. One is the required fitting-out of the suroundings, which is difficult on a building construction site. A work site of building construction changes continuously and permanent marks, such as ultra-sonic beacons, are not suitable.

The second is the accuracy of ultra-sound location devices, which is very sensitive to angular incidence and relative position of the vehicle in the room. In most positions, ultra-sound based system provide distance measurements with significant errors.

We have noticed that, even with standard plaster boards, the ultra-sonic telemeters indicated correct distance measurements, when the ultra-sonic wave was nearly normal to the surface. We then developed a positioning system with ultra-sonic sensors that are always in these good measurement conditions.

3. Design of a new ultra-sonic positioning system

3.1. System description

The aim of the system presented below is to gather simplicity of ultra-sound system with maximum accuracy.

Emitter and receiver are set on the mobile, so no specific adaptation of the environment is required.

For high accuracy, ultra-sonic sources can rotate in order to find the best measurement conditions.

The basic idea is that the position of the robot is known as soon as two distances normally to two walls are measured (see Fig. 5).

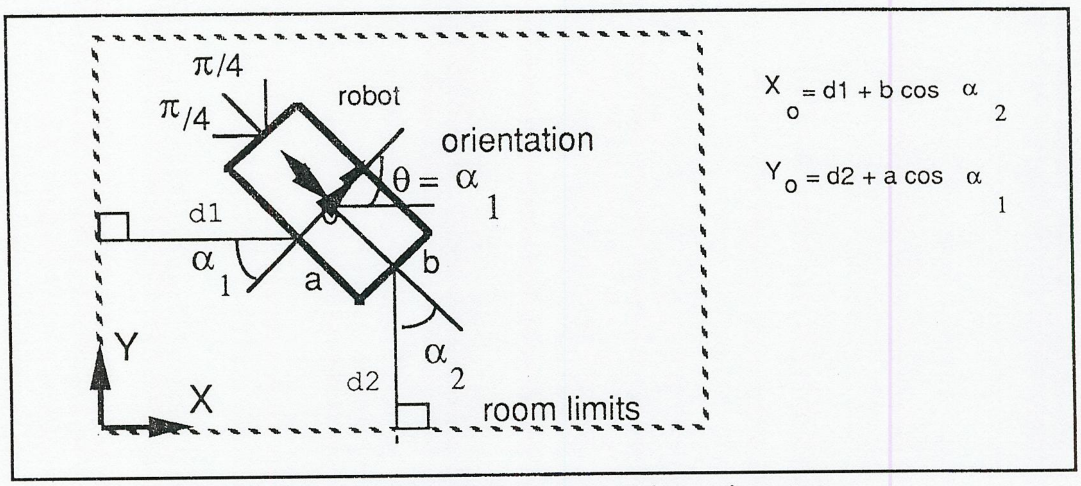

Figure 5 Positioning with ultra-sonic rotating telemeters.

Of course, two angles must also be known which indicate the direction of ultra-sonic beams in the robot coordinate system.

In order to cope with particular room architectures, four sensors should be used. They are to be placed on the four sides of a mobile robot when the general shape of the platform is rectangular.

Stepping motors suit perfectly for experiments. We have chosen a 200 steps/revolution stepping motor. The angles are directly measured by counting the steps.

The determination of the perpendicular to the wall surface has been carried out by two methods :

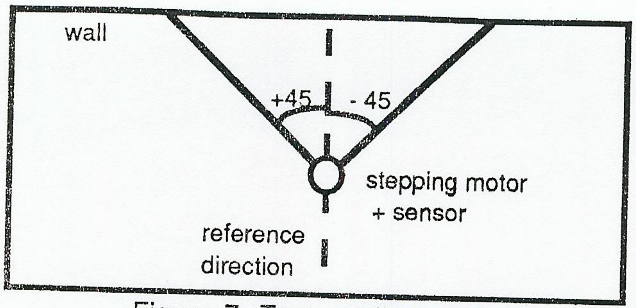

Figure 7. Test configuration.

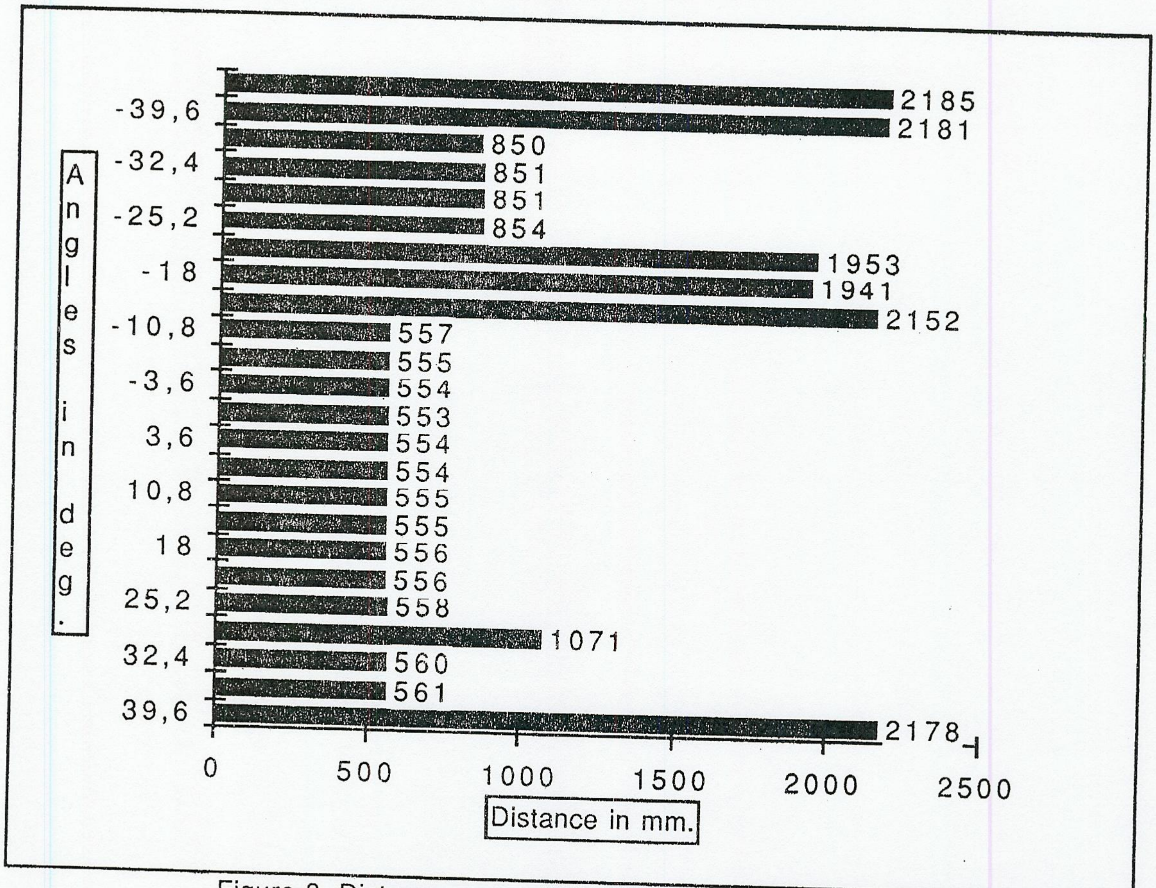

Figure 8. Distance measurements by a rotating sensor.

Other tests have been performed for different other configuration (corner). Very often several local minima appears in the set of measurement but the algorithm should only consider the low flat minimum zone which indicates that the sensor is orthogonal to the reflecting wall.

4. Conclusion

The design of the positioning system is based on a rather conventional principle. Ultra-sound transmitter and receiver are set on the vehicle in order to avoid surrounding adaptation.
The originality comes from the rotating sensors which improve standard accuracy of ultra-sound distance measurements.

Robust and accurate enough, such a device seems suitable for positioning of mobile robots in a building environment and especially for construction tasks.

- a least square method to determine an image (line) of the wall from distance measurements through a scanning period. The slope of this line, and then the slope of the perpendicular are easily calculated ;

- a direct determination of the minimum distance to the wall from the analysis of the distance variations gradient .

The second method is simpler and better.

The experimental rig consists of an ultra-sonic system developed by ROBOSOFT and of two CPU boards. One is dedicated to motors control and the other to supervision and position calculation.

The motors have vertical axis and rotate the ultra-sonic sensors within a range of $-\frac{\pi}{4} + \frac{\pi}{4}$ radians centered on the normal to the robot side (see Fig. 6).

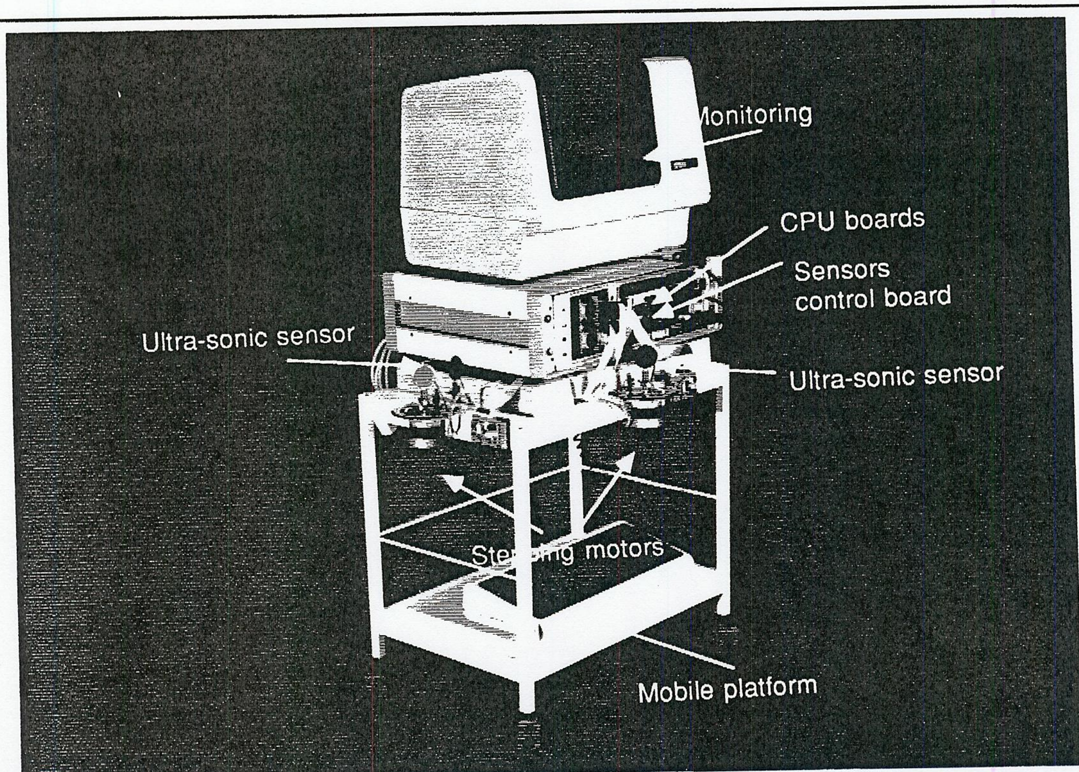

Figure 6. View of the experimental system.

This positioning system is well suited for construction sites applications in the way it uses the spatial structure of the building under construction.
A limitation may come from the ultra-sonic sources which are present on a site (air compressor, high pressure air leaks, ...).
Further tests are under progress in laboratory to qualify the robustness of this system under such disturbances.

3.2 Experimental results

The following table shows some experimental results in a conventional case. The rotating sensor is facing a wall (fig. 7) and scans in every directions from - 45 deg. to + 45 deg. From the set of measured distances (fig. 8) and after minimum extraction by suitable algorithm, the precise distance to the wall and the angle are known.

5. Bibliography

[1] SALICHS and al..-"Ultrasonic beacons system for mobile robots", in : International Workshop on Sensorial Integration for Industrial Robots, IEEE , Saragoza, 22-24 November 1989.- Zaragoza, Publicaciones de la Universidad, 1989

[2] LAHARY (B.).- "Commande d'un chariot mobile".- Rapport de stage ENSMP/CSTB, Valbonne Sophia Antipolis, CSTB, July 1986

[3] TSUZUKI and al..- "A sonar based environmental sensory system for mobile robots", in : International Workshop on Sensorial Integration for Industrial Robots, IEEE, Saragoza, 22-24 November 1989.- Zaragoza, Publicaciones de la Universidad, 1989

[4] CROWLEY (J.).- "World modeling and position estimation for a mobile robot using ultra-sonic ranging", in International Workshop on Intelligent Robots and Systems'89 ,IEEE/RSJ . TSUKUBA, 4-6 September, 1989.- Piscataway (USA, IEEE, 1989

[5] DURANT-WHYTE (H.), BRADY (M.).- "Mobile robot research at the University of Oxford".- in : International Workshop on Sensorial Integration for Industrial Robots, IEEE , Saragoza, 22-24 November 1989.- Zaragoza, Publicaciones de la Universidad, 1989

[6] SALAGNAC (J-L.) and al..- "SOFFITO : a mobile robot for finishing works in buildings", in : Fifth International Symposium on robotics in construction, JIRA, Tokyo, 6-8 juin 1988.- Tokyo, JIRA ,1988

[7] CROWLEY (J-L.).- "Navigation and World modeling for a mobile robot : a progress report" in : colloque CAO et Robotique en Architecture et BTP, Marseille, IIRIAM, CSTB, GAMSAU, 26-28 juin 1986.- Paris, HERMES, 1986