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CONTROL OF A MEDICAL AID MOBILE ROBOT BASED ON A FUZZY NAVIGATION.

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ABSTRACT

Some disabled people can't use properly their hands and legs. Artificial arms exist and it could be interesting to put them on a mobile platform to help those people to gain some autonomy. Our purpose is to develop this mobile platform and its command with special constraints. Most of the motion controls of the mobile robots are based on the classical scheme planning-navigation-piloting. The navigation function, the main part of which consists of obstacle avoidance, has to react quickly with the shortest response time. The real time constraint hardly limits the complexity of sensor data processing. The described navigator is built around fuzzy logic controllers. Besides the well-known possibility of taking into account human know-how, the approach provides several contributions : a low sensitivity to erroneous or inaccurate measures and, if the inputs of the controllers are normalised, a well to do portability on another platform. That allows a cost reduction in medical systems for disabled people. To show these advantages, the same fuzzy navigator has been implemented on two mobile robots. Their mechanical structures are close except for the size and the sensing system.

1. INTRODUCTION

Over the past few years, the research in autonomous mobile robot field gained an extensive interest. This is due chiefly to the necessity to replace human intervention in dangerous environments (nuclear, space, ...), or to the wish to develop an help in some more classical tasks (cleaning, supervision, carriage, ...).

A new kind of application is appearing with the assistance to disabled people. Different people have worked on the wheelchair driving assistance ([HoRi94] for example). An idea is proposed by AFM (Association Française contre les Myopathies, a French association) : the use of a mechanical arm, called Manus, installed on the wheelchair (Fig.1).

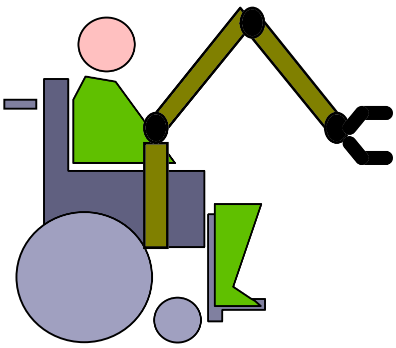

Figure 1 *: wheelchair carrying an arm.*

This will help people with a sever handicap to interact with their environment and obtain a certain autonomy. The AFM has tested it for months by equipping for full time one people's chair. Two major drawbacks appear :

- the arm's weight (about 15kg) unbalance the wheelchair and it was then impossible to go outdoor with it ;
- many people, because of a corset, can't watch the floor near their wheelchair so can't take or put anything on the floor.

To cure those problems, the AFM has proposed to install Manus on an independent mobile platform (Fig.2).

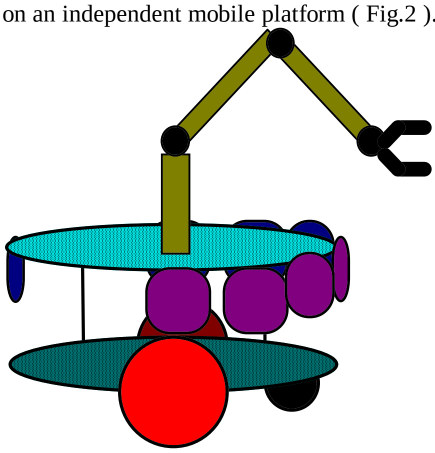

Figure 2 *: mobile platform carrying an arm.*

The first step the AFM has fixed consists on manipulating objects in the same room but far away from the people. The second one involves in the same manipulation but in the nearby room. In that second case, a suitable autonomous mobile robot is necessary to perform realistic trajectories without any danger for the human supervisor and a sufficiently large percentage of success.

Our problem is then to develop an algorithm to control efficiently the robot displacements. Different constraints are to be taken in account :

- the cost pushes us to choose low cost sensors regardless their performances ;
- the use in different situations impose a portable set of algorithms on different systems ;
- the human presence requires a high level of security ;
- the human supervision calls for a specific Man Machine Interface (MMI) and permits us to avoid keeping in mind some very difficult case of navigation uncertainty.

In section 2 we present different methods for the control of mobile robot. Then, in section 3, we expose our method. To ensure the portability, we don't use artificial landmarks but only measurements from ultrasonic sensors and odometry. We improve our algorithm by testing it on two different robots. Those robots are described in section 4. Our specific robot uses 8 ultrasonic sensors and odometry while the other one, named Khepera®, uses infrared sensors and odometry. The results are presented in section 5. We then conclude and expose the directions of our future works in section 6.

2. VARIOUS APPROACHES

Various methods for controlling mobile robot systems have been developed which are generally classified in two categories : global planning and local control.

Many works, based on the complete knowledge of the robot and the environment, use a global planning method such as artificial potential fields [KHA 86], connectivity graph, Voronoî diagram, cell decomposition [LAT 91] [TOU 92], ... Those methods build some paths (set of subgoals) which are free of obstacles. Their main advantages are to prove the existence of a solution which permits to the robot to reach its destination and to generate a collision-free map-making. Thus, in this map, a global optimal solution can be achieved with the assistance of a cost function which related to either the global route between a start position to a goal position thanks to the A*-algorithm for example, or the time path or even the safe mission [MEY 91]. However, they have some well-known drawbacks. For example, an exact model of the environment is needed which unfortunately can not be defined in most applications. A modification of the environment due to some new dynamic objects can not be correctly handled.

The local methods are mainly used in unstructured environment. They might be called reactive strategies and are based completely on sensory information. So, an absolute localisation is not requisite and only the relative interactions between the robot and the environment has to be assessed. In these circumstances, a structural modelling of the environment is unnecessary, but the robot has to have by its sensory inputs a set of stimulus-response mechanisms. In this scheme, the robot is generally expected to do only simple tasks. Numerous methods have been proposed [BRO 86][BOR 89].... The main disadvantage of these methods is to not guarantee a solution for the mission because of the occurrence of deadlock problem. The reason is the robot does not have a high-level map-reading ability. For more efficiency and safe, perception tools have to be increased (several types of sensors including cameras) to get more pertinent information about the environment. But, the data are not easy to process under real time constraints. Those constraints often lead to a degradation of the accuracy and the richness of the information.

The use of only one among these methods for the control motion of a mobile robot in a complex environment, is turned out to be insufficient and hazardous. In fact, some constraints are added to their intrinsic drawbacks caused by :

-the imprecision or lack of knowledge in understanding all the phenomena contributing to the system's and environment's behaviour ;

-the difficulties to correctly represent the environment and to locate the robot due to errors in the sensors data which are still far from perfect taking in account the present day technologies.

A set of methodologies called qualitative or approximate reasoning have been developed to build decision-making approach in systems where all uncertainties can not be completely avoided or corrected. These methologies attempt to capture some aspects of the human behaviour in system control. Their aim is to incorporate implicitly the uncertainties in the information gathering and reasoning process, rather than to determine explicitly them through numerical calculations or mathematical representations.

Some qualitative reasoning theories have been developed over the past few years [KAN 88] and the most actually used for application to control systems is the theory of fuzzy sets [ZAD 65]. The control based on this theory [LEE 90] provided satisfying results [MAA 93][BAR 94] in cases where classical control failed. The fact that a fuzzy controller is built following the knowledge of experts. So, a complex or ill-defined system can be described without using an exact mathematical model.

Therefore, fuzzy sets theory is a good candidate both to handle different sources of imprecision and to assign built-in guidance control enabling the robot to navigate throughout complex environments. In fact, we know from our own experience of human motion that it is unnecessary to know either our own exact location or to have a comprehensive knowledge of the whole scene. It can be sufficient for example to know whether there is enough free space to get around an obstacle and to recognise marks indicating whether the passageway leads to the goal or not. Many application works of fuzzy logic in the mobile robot field have given promising results [URA 76][SUG 85][TAK 88][MAE 90][HIR 89][PIN 92].

3. CONTROL ARCHITECTURE

To draw near to human being behaviour, the efficient control of a mobile robot motion in complex environments needs a hierarchical strategy :

- a high level for planning path using global description of the world with possibly incomplete and/or imperfect knowledge ;
- a local level where the robot moving is based completely on information of different sensors which cover the close circle of the vehicle.

Therefore, to generate successfully the trajectory of a mobile robot, our approach is to propose an hybrid method. Based on the pre-acquired knowledge of the environment a planner is used to give subgoals and a navigator to realise the local control (Fig.3).

The "portability" of algorithms developed following these methods is proved by applying them to two distinct mobile robots equipped with two different sensors types : the miniature robot Khepera and a laboratory design robot RMI.

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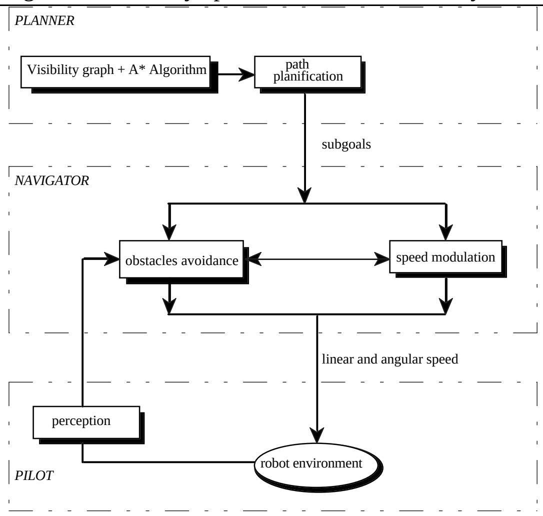


Figure 3. *Global scheme*

Planner: Visibility graph + A* Algorithm

The global method provides the planning of path by the visibility graph [LAT 91] and the algorithm A* using the euclidian distance. This cost function could be transformed to avoid certain congested places or to get through easy measured ones for a best localisation.

Navigator

When the vehicle is moving towards the target (once of subgoals or final target) and the front sensors detect an obstacle even located on the path, an avoiding strategy is necessary. The selected method consists in reaching the middle of a collision-free space. The used navigator is built with a fuzzy controller based on a set of rules with as follows :

rule R_i "**If** Rn is x_i **and** Ln is y_i **Then** ω is t_i
and if Fn is z_i **then** v is u_i ".
Else

rule R_{i+1} "**If**..."

x_i, y_i, z_i, t_i and u_i are a linguistic labels of a fuzzy partition of respectively the universes of discourse of the inputs Rn, Ln and Fn and the outputs ω and v. The inputs variables are respectively the normalised measured distances on the right R, on the left L and in front F such as :

$$R_n = \frac{R}{R+L},\ L_n = \frac{L}{R+L} \text{ and } F_n = \frac{F}{\inf}$$

where inf is the sensor maximum range.

Thanks to this normalisation, the universe of discourse evolves with the sensors range (Fig.4).

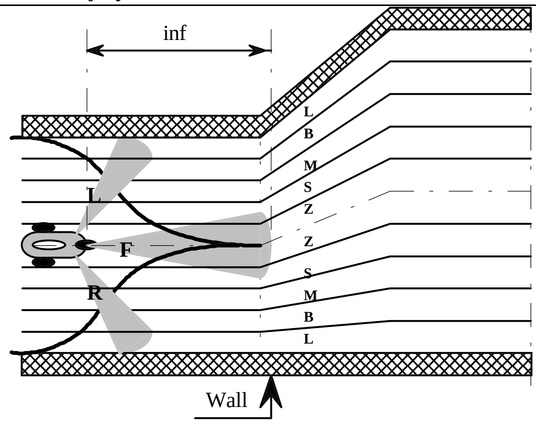


Figure 4. *Evolution of the universe of discourse partition*

The output variables are the angular and the linear speeds (Fig.5). On simplicity ground, the shape of the membership functions is triangular and the sum of the membership degrees for each variable is always equal to 1. The universes of discourse are normalised between -1 and 1, for ω, and 0 and 1 for the other ones.

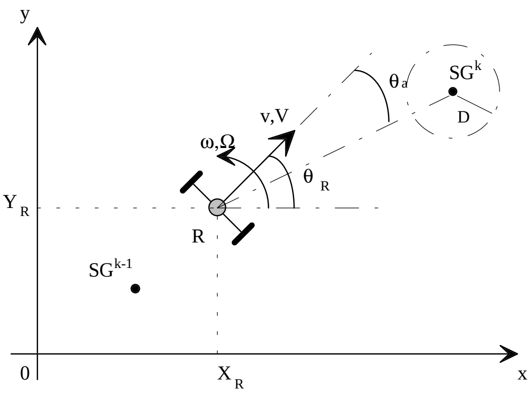
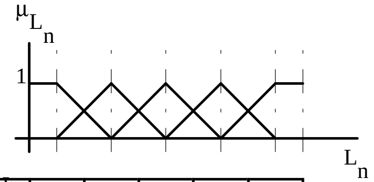


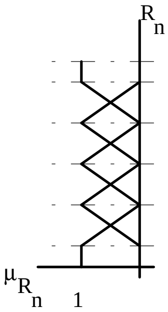
Figure 5. *Localisation of the robot*

Each universe of discourse is shared in five fuzzy subsets. The linguistic labels are defined as follows:

Z	: *Zero*	NB	: *Negative Big*
S	: *Small*	NS	: *Negative Small*
M	: *Medium*	Z	: *Zero*
B	: *Big*	PS	: *Positive Small*
L	: *Large*	PB	: *Positive Big*

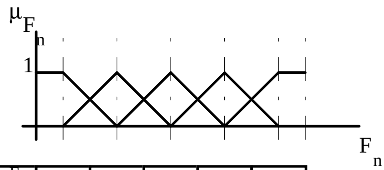
The whole control rules deduced from a human driver's intuitive experience is represented by fifty rules shown in the two following decision tables (Table1 and Table2) : 25 rules allow to determine the angular velocity w and 25 others determine the linear speed v.

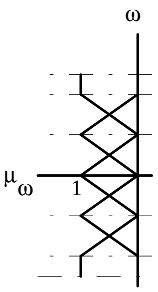




R_n \ L_n	Z	S	M	B	L
Z	**Z**	**PS**	**PS**	**PB**	**PB**
S	**NS**	**Z**	**PS**	**PS**	**PB**
M	**NS**	**NS**	**Z**	**PS**	**PS**
B	**NB**	**NS**	**NS**	**Z**	**PS**
L	**NB**	**NB**	**NS**	**NS**	**Z**

Table 1. *Angular velocity rules*





ω \ F_n	Z	S	M	B	L
NB	**Z**	**Z**	**S**	**S**	**S**
NS	**Z**	**S**	**S**	**B**	**B**
Z	**Z**	**S**	**M**	**B**	**L**
PS	**Z**	**S**	**S**	**B**	**B**
PB	**Z**	**Z**	**S**	**S**	**S**

Table 2. *Linear speed rules*

An example of fuzzy rules such is :

⊇ **If** (R_n is *Large*) **and** (L_n is *Large*) **then** (ω is *Zero*) **and if** (f is *Large*) **then** (v is *Large*).

⊄ **If** (R_n is *Large*) **and** (L_n is *Small*) **then** (ω is *Positive Big*) **and if** (f is *Zero*) **then** (v is *Zero*).

The operators used are similar to those appearing in a Mamdani's controller : MIN for the composition of the input variables and for the fuzzy implication and MAX for the aggregation of the rules. In order to determine the crisp output actions ω (Fig.6) and v (Fig.7), the centre of gravity [LEE 90] is used as a defuzzification method.

$$\omega^k = \frac{\sum_{i=1}^{i=n} \omega_i . \mu_{\omega i}}{\sum_{i=1}^{i=n} \mu_{\omega i}} \text{ and } v^k = \frac{\sum_{i=1}^{i=n} v_i . \mu_{\omega i}}{\sum_{i=1}^{i=n} \mu_{\omega i}}$$

where n and m denote respectively the number of quantization levels of the fuzzy output actions ω and v.

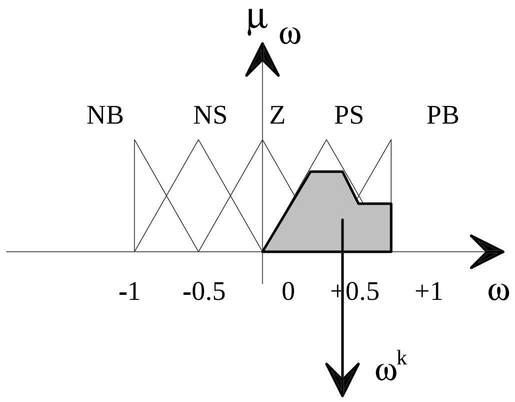


Figure 6. *Angular speed membership functions*

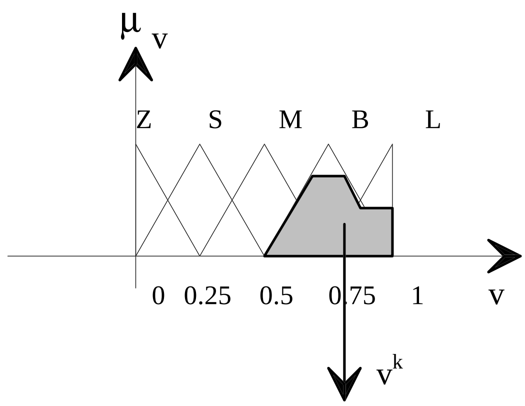


Figure 7. *Linear speed membership functions*

The ω and v control actions produced by the controller handle the robot to avoid the obstacles when it is attracted by the immediate nearest subgoal (SG^k). This latter exercises an attractive force which guides the robot until its destination. The actions (ω_a and v_a) generated by this force are modulated by the inverse of the distance $\left\| R, SG^k \right\|$ between the centre of the robot and the k[th] subgoal (Fig.5).

$$\text{If } \left((L_n \notin [0.2;0.4]) \text{ or } (R_n \notin [0.2;0.4]) \text{ or } (F_n < 0.2) \right)$$

$$\text{then : } \quad \omega_a = 0 \quad \text{and} \quad v_a = 1$$

$$\text{else if } \left(\left\| R, SG^k \right\| > D \right)$$

$$\text{then : } \quad \omega_a = \frac{C_{at}}{\left\| R, SG^k \right\|} \theta_a \text{ and } v_a = 1 - \omega_a$$

$$\text{else : } \quad \omega_a = 0{,}5 . \theta_a \quad \text{and} \quad v_a = 1 - \omega_a$$

The setpoints V and Ω applied to the robot result of a linear combination between the obstacles avoidance and the subgoal attraction.

$$\text{If } \left(\left\| R, SG^k \right\| < D \right) \text{or} \left(\left\| R, SG^{k-1} \right\| < D \right)$$

$$\text{then } V = Min(v, v_a).V_{\min} \ (m/s)$$

$$\text{else} \quad V = Min(v, v_a).V_{\max} \ (m/s)$$

$$\Omega = \beta \left(\omega + \alpha \omega_a \right) \quad (\text{rd/s})$$

where Cat, α and β are coefficients adjusted by experimentation to get the best trajectory generation.

Pilot

The robot's V (linear speed) and Ω (angular speed) are send to an onboard micro processor. The linear speeds of the right and left wheels are then calculated. A low level feedback loop is then performed on the robot itself by a PID controller.

4. PHYSICAL IMPLEMENTATION

Khepera

Physical structure : Khepera® is a small mobile robot developed at Ecole Polytechnique Fédérale de Lausanne (EPFL). With a circular shape featuring 55mm of diameter, 30mm of height, and 70g of weight [MON 93], it is supported by two wheels and two small Teflon balls (Fig.8). The wheels are controlled by two DC motors with an incremental encoder (12 pulses per mm of robot displacement).

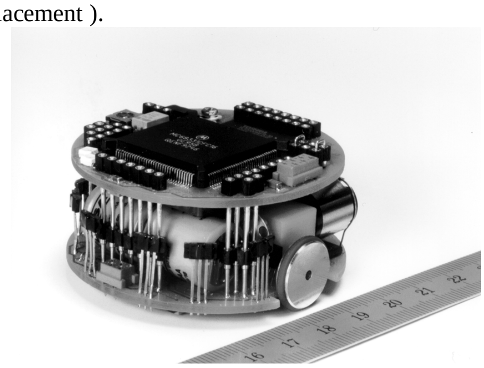


Figure 8. *the miniature mobile robot "KHEPERA"*

Perception : The robot possesses eight infrared sensors, which emit infrared light, measure the reflected light and return a corresponding value in the range [0, 1023]. They are disposed in a somewhat circular fashion around its body and allow the measurement of distances in a short range from about 1 to 5 *cm*.

Hardware structure : The on-board computer is based on a Motorola 68331 micro-controller.

R.M.I.

Physical structure : R.M.I. (French acronym for Intelligent Mobile Robot) is a two back wheels circular robot. It is twenty centimetres high and twenty centimetres of radius and can carry about ten kilograms weight.

The wheels are controlled by two DC motors with an incremental encoder (17 pulses per mm of robot displacement).

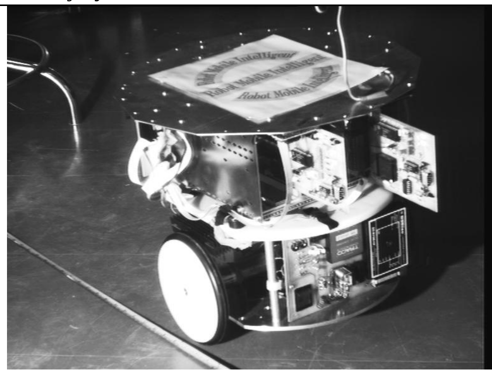


Figure 9. *The robot RMI.*

Perception : The robot carries eight ultrasonic Polaroid sensors around its body : seven in front, one behind (fig.11). The cone half-angle of the sensors are about 15 degrees. The accuracy is better than 3 centimetres at 3 meters. A major drawback is the blind zone due to the fact that transducer alternatively plays the part of transmitter and receiver. The blind zone at the present time is about 45 centimetres long but can be reduced to 16 centimetres by using a more complex control electronics. The range is about 10 meters.

Hardware structure : The on-board computer is built around a set of processor boards. Each board is dedicated to a function : motors control, perception, planification and navigation.

Up to present time, the serial RS 232C communication has imposed a master-slave architecture. But a network-based solution is available now and allows the implantation of less hierarchical structures.

Fuzzy controller inputs

The previous described navigator uses effectively three normalised inputs : front (F), left (L) and right (R). As both robots possess more than three sensors the three inputs has to be computed.

In the Khepera case : each input is the minimum value given by a set of infrared sensors :

front input F = Min(IR0, IR7),
right input R = Min(IR5, IR6, IR7),
left input L = Min(IR0, IR1, IR2).

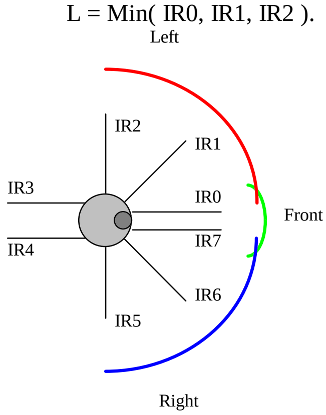


Figure 10. *Infrared sensors layout*

In the RMI case : each input is the minimum value given by a set of ultrasonic sensors :

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front input F = Min(USd, USe, USf),
right input L = Min(USf, USg, USh),
left input R = Min(USb, USc, USd).

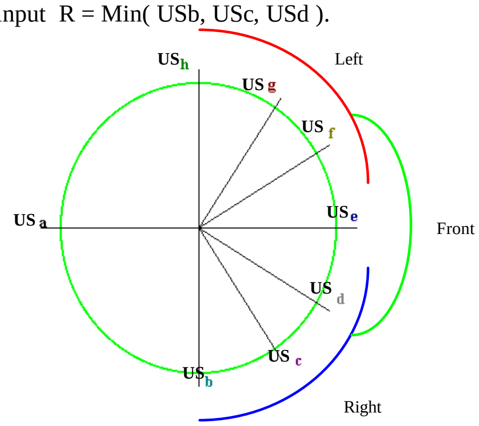

Figure 11. *Ultrasonic sensors layout*

5. EXPERIMENTATION RESULTS

The task consists in getting through a doorway in a partially known environment as a flat. Only some pieces of furniture are unknown for example chairs, table ...
The experimental environment is composed of a room with or without obstacles. From an ideal path given by the planificator (fig 12) how do both robots operate?
The following section describes the behaviour of both robots in the same environment (with respect to their dimensions).

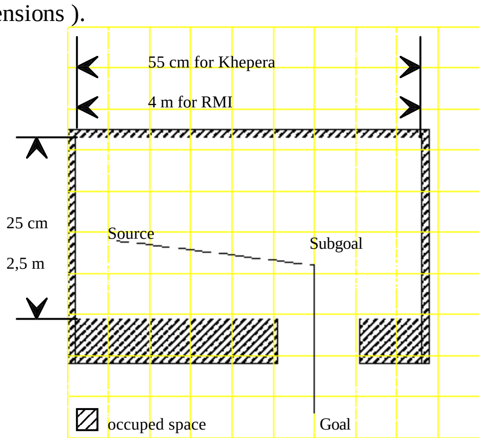

Figure 12. *Planned path*

Khepera
The environment of Khepera is composed of a set of polygonal boxes representing the walls and the obstacles. The room is 55 cm long and 25 cm wide.
As the range of the infrared sensors is limited to 5 cm, the robot cannot see all the walls. Since the inputs of the fuzzy controller belongs to the subset large while the deviation to the subset zero, the robot converges to the subgoals at the maximum speed. Only the significant measurements are drawn on the figure. Since the width of the door is about 11cm wide the edge of the door are well-seen by the sensors.
As illustrated in figure 13 the obstacle is well identified by the sensors.

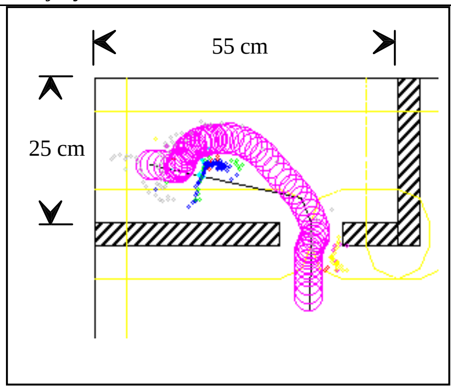

Figure 13. *Navigation with an obstacle beside the door*

Thanks to fuzzy navigator the robot avoid the obstacle in spite of the short range of the infrared sensors (5cm). After obstacle avoidance the robot converge toward the next subgoal.

R.M.I.
The room is about four meters long and two and a half meters wide. The door is ninety centimetres wide.
Four different points should be notice. Firstly, in spite of several wrong measurements generally due to multi-echoes, the fuzzy navigation succeeds the plan.
Secondly, the measurements, labelled for each sensor by a letter, provide an accurate information on the wall position. It allows to locate precisely the robot.
Thirdly, the sensors detect the stiles of the door very soon. Even if the odometer gives an inaccurate robot position, it is possible to locate the robot and to get through the door.

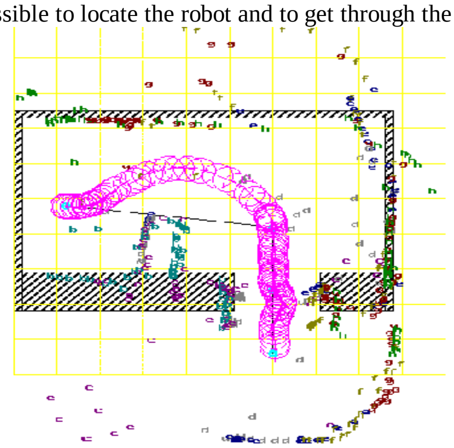

Figure 14. *Navigation with an obstacle beside the door*

Finally, the obstacle is well-localised (Fig.14) by the sensors and appears clearly in the environment representation. The obstacle avoidance doesn’t prevent the robot from getting through the door. The spatial layout of the sensors seems to be self-sufficient.

6. CONCLUSION

Fuzzy navigator integrates heuristics copying human behaviour. It is divided into two fuzzy controllers to generate angular and linear speeds of the robots separately. Both actions are then combined in order to deduce angular speed of each wheel.
The navigator has been implemented on two mobile robots.

In the case of the ultrasound sensing system - generally due to multiple echoes - the rate of erroneous measures is high. Nevertheless the robot carries out its task of passing through a doorway in spite of obstacles unknown by the planner.

Besides the high insensitiveness to erroneous or inaccurate measures, the navigator presents the advantage to be easily portable on another platform. This has been shown implementing the previous navigator with the same adjustings on a robot which size and sensing system are quite different. Only the measures has been normalised by the range of the sensors. Indeed the normalisation of the fuzzy inputs ensures an homothetic invariance. So the size of the robot do not change the control. The higher semantic level of the inputs (left, right and front) allows the use of different types of sensors (ultrasonic and infrared).

The developed robot is destined to provide an aid for disabled people. It remains to validate the approach in a more complex environment such as a flat. The treating of some special cases : legs of a chair, narrow doorway, frequent turns sets the problem of the absolute localisation with a poor perception system. The all work about the MMI is to be developed too.

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