P. Hoppenot, E. Colle: "Robotics Assistance to disabled and elderly people" - IMACS'2000, Lausanne, Session 170, abstract, pp.261, 21-25 August 2000.

ASSISTANCE MOBILE ROBOT TO DISABLED PEOPLE

Philippe HOPPENOT, Etienne COLLE.
CEMIF - Complex System Group - University of Evry, 40, rue du Pelvoux, 91020 Evry Cedex, France.
e-mail: hoppenot, ecolle | @cemif.univ-evry.fr

ABSTRACT

Disabled people assistance is developing thanks to new technologies. Mobile robotics is one of them. Low cost constraints impose the choice of sensors of mean capacities perception: ultrasonic sensors, odometry and low-cost camera (information feedback and goal-tracking). The approach is developed in two steps. The first one consists in giving maximum autonomy capacities to the robot (planification, navigation and localisation). The second step is the study of the Man-Machine Co-operation (MMC). Indeed, the aim is to perform a mission (mobile robot displacement) with the robot capacities and the man possibilities. The main problem is then task allocation between the two intelligent entities. Each one has planification, navigation and localisation abilities. Enhanced reality techniques are used in the Man-Machine Interface (MMI) to present feedback information to the human supervisor (ultrasonic sensors measures on the flat plane). Video image feedback permits the person immersion in the robot reality during the mission. A more specific study has been performed about the localisation error detection which is very important to automatic planification and navigation.

INTRODUCTION

The emergence of robotic solutions in disabled people aid tasks is realistic under only two conditions. The first one concerns the very principle of the aid. The system must not « do for » but compensate the action deficiency of disabled people. So, that implies a man-machine co-operation. The person intervention degree begins with the simple contribution in perception or decision functions and ends with machine teleoperation. The partial autonomy of the system completes the field of people abilities either to palliate deficiency due to the handicap or to realise tedious actions.

The second condition is the cost of the assistance. This strong constraint limits the autonomy degree of the system by the reduction of perception ability and computing power. In that case, the man-machine co-operation permits to balance the machine deficiencies by the perception, the decision, and to a minor extent the action means of the person.

Among the main today's life functions listed by WHO (World Health Organisation), several actions like carrying, grasping, picking up, moving, are "robotisable". Different kinds of project have been presented in [Kawamura94]. First ones are workstation-based systems. A table-mounted robot arm works in an environment where the position of different objects are known by the system. HANDY1 ([Topping98]) and DeVAR ([Vanderloos95]) are two examples. Second kinds of projects are stand-alone manipulator systems where the object position is not known. This allows more flexibility but needs sensors for the environment perception: Tou system ([Casals93]) and ISAC ([Kawamura94b]). Other solutions are wheelchair-based systems. The most well known system is MANUS ([Jackson93]). Mobile robot systems are also used: WALKY ([Neveryd95]), Health Care Robot ([Fiorini97]), URMAD ([Dario95]) and MOVAID ([Guglielmelli96]). The last kind of systems proposed are collaborative robotic aid systems where multiple robots perform several tasks for the user ([Kawamura93]).

Under both conditions seen before, not «do for» and «not cost too much», a mobile robot is developed with AFM (French Association against Myopathies). The mission consists in carrying an object in a partially known environment such as a flat. The flat plan is known but table, chair are not modelled and are considered as obstacles. The deficiencies of the man and the machine are palliated by a well-suited co-operation. During the progress of the mission the main goal is to dispatch operations between the person and the machine ([Crevits95]). The task allocation depends on numerous factors : i) at person level, handicap degree and tendency to get tired, ii) at machine level, abilities and performances, iii) at mission level, task type and task development - correct or not correct.

The moving of a mobile robot can be divided into three tasks: planning, navigation and localisation. Planning determines the best path to go from one point to another. Navigation ensures the robot follows the path avoiding obstacles. Localisation gives the position and the orientation of the robot inside the flat at any time.

The paper describes the Man Machine Co-operation (MMC) for the three tasks. After presenting the system architecture, the following section analyses the different command modes of the machine and the intervention degree of the person inside each mode. Then the MMC is described for each function: planning, navigation and localisation. Two planning strategies are considered in section 3 where the intervention of the person is variable. Section 4 is interested in the navigation which can be completely automatic or manual assisted by some functions of the machine such as obstacle avoiding. Section 5 develops localisation which requires the closest man machine co-operation because of the difficulty of the operation.

ASSISTANCE SYSTEM ARCHITECTURE

The aid system is composed of a control-command station for the person and a manipulator arm mounted on a mobile robot (Figure 1).

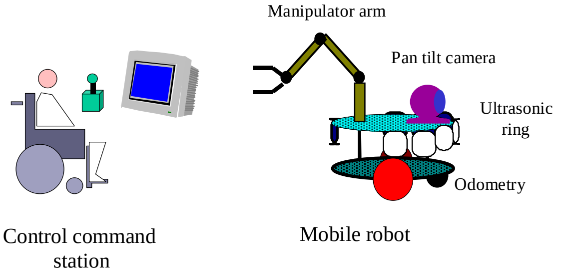


Figure 1 : *System architecture.*

Mobile robot

In order to « not to cost too much » the robot has limited and poor perception means at its disposal, an odometer and an ultrasonic ring. Odometry gives the position and the orientation versus angular rotation of the wheels. The method is simple and low cost but presents a systematic error which depends on the distance and a non-systematic error mainly due to wheel spin and sliding. Ultrasonic ring measures the distance between the robot and obstacles all around the robot. Generally the ultrasonic technology is limited to proximetry because of medium metrological characteristics and a high rate of erroneous measures. The algorithms must operate in those difficult conditions.
The camera mounted on a pan and tilt base is a commercial device dedicated to general surveillance applications. The unit presents a smart feature : the auto-tracking mode. The camera automatically follows the movement of an object. The camera plays two roles: i) the video feedback during the robot displacement, ii) the pointing out of a direction or thanks to the auto-tracking the following of an object. In the last case the robot is driven by the camera.

Control-command station

The Control-command station is composed of a screen which displays different types of information via enhanced reality techniques (Figure 2):
i) feedback information such as video image of what is seen by the robot, the robot position on the 2D flat plan or robot operating indicators.
ii) complementary command information such as command modes. The person disposes of three command modes to direct the mobile robot.

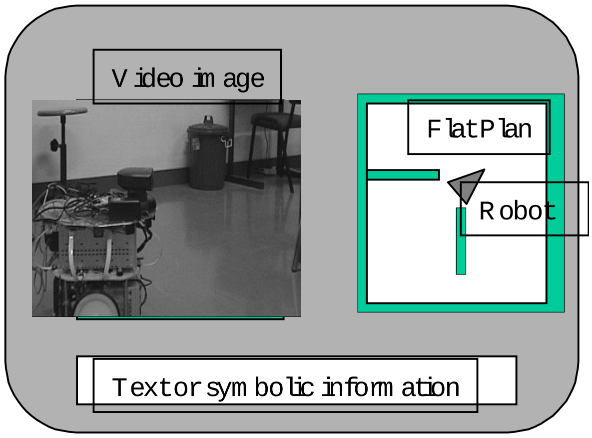


Figure 2 : *Enhanced reality approach for the feedback information.*

In mode 1 the person points out the destination on the 2D flat plan displayed on the screen. The robot automatically reaches the position avoiding obstacles.
In mode 2 the person points out a direction or an interesting object on the video image. He defines the goal driving the tilt and pan base of the camera. The auto-tracking function of the camera directly pilots the robot when the destination is an object.
In mode 3, the person teleoperates the robot « manually » via a joystick or any command device. An assistance to automatically avoid obstacles may be available.

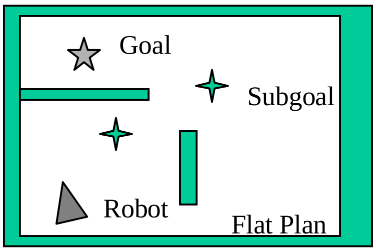
TASK ALLOCATION

Different scenari are conceivable to pilot the robot following the command mode and the degree of person intervention during the task execution in accordance with the handicap degree and the tendency to get tired. The person intervention can be classified in three levels : i) supervision which uses perception and decision functions to elaborate a diagnostic during the execution of the task., ii) control/command which uses perception-decision-action either to define a goal or iii) to manually pilot the robot.
As seen in the introduction the mission « move the robot from one point to another » implies three main functions: planning, navigation and localisation. Table 1 resumes the intervention level of the person during the involvement of the mission.

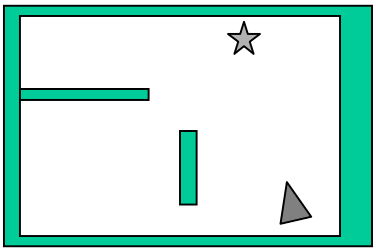
Table 1 : *Co-operation between man and machine.*

PLANNING

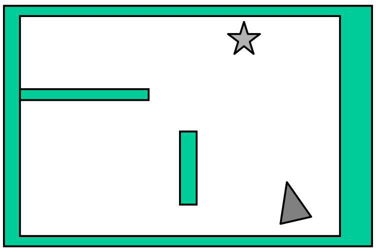
This is the first step to execute a mission. Man and machine have capacities to determine the way to follow in the flat. In all three modes defined above, the person gives the goal (Figure 3).



Mode 1: the person defines the goal on the flat plan.



Mode 2: the person defines the goal on the video image. The camera uses the autotracking function.



Mode 3: the person teleoperates the robot. The camera is used only for feedback.

Figure 3 : *Path planning following the command mode.*

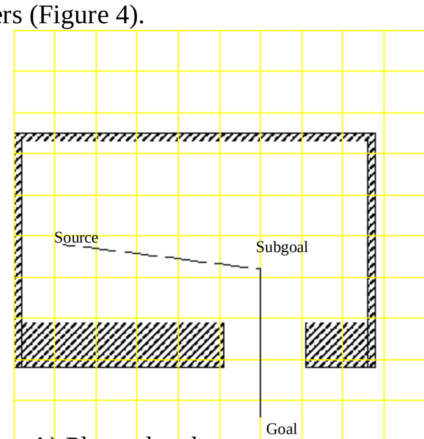
In mode 1, the goal designation can be of very low level. The person gives the position of the goal by pointing it out on the plane drawn on the screen. But the designation can be of higher level. If the person wants to go to the fridge, the goal is defined, the machine computes intermediate subgoals using the knowledge of the environment. The planning method is based on the visibility graph and the A* algorithm ([Benreguieg97]). It is also possible for the person to give some subgoals before the computing of the machine.

In mode 2, the person points out a goal with a camera. The goal must be in the vision field of the camera. The camera tracks the object and automatically points out on it with pan and tilt moves. The robot moves in the direction pointed out by the camera. This is a human like behaviour where the object is considered as a target which can be mobile. In that case, intermediate subgoals are not useful. The remaining issue is only to avoid obstacles on the path. This is a navigation problem.

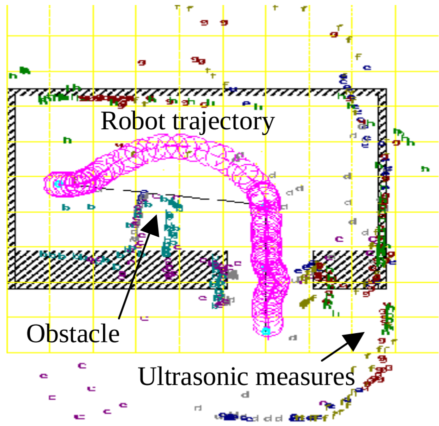
In mode 3, planification is performed on line by the person who drives manually the robot. The camera in then used only to return visual information.

Navigation

The problem is to follow the planed trajectory. The navigation is divided into two behaviours: goal-seeking and obstacle avoidance. A fusion of those two behaviours is achieved to provide the robot move orders (Figure 4).



A) Planned path



B) Robot navigation with obstacle avoiding

Figure 4 : *Fusion of two behaviour, obstacle avoiding and goal-seeking for robot navigation.*

Entirely automatic navigation can be performed in modes 1 and 2. Goal-seeking depends on the relative positions of the robot position and the next subgoal which define the direction to follow and the speed (depending on the distance). If an unmodeled obstacle stands on the robot path, it must be avoided. Ultrasonic sensors detect these obstacles and fuzzy logic manages the obstacle avoidance. The aim is to create a human like behaviour by passing as far as possible from obstacles. The fusion of those behaviours is realised by taking into account only obstacle avoidance when an obstacle is near the robot. When the distance between obstacles and the robot grows up, goal-seeking behaviour takes more

importance in the robot command. All these results are detailed in [Benreguieg97].
In mode 3 the person drives directly the robot, goal-seeking behaviour is then disabled. Nevertheless obstacle avoidance can be available to help the driver. In that case, the person gives only a direction to follow (with a joystick for example) and the robot avoids itself the obstacles. This a very appreciable help especially when the robot is in another room out of the field of the person vision.

LOCALISATION

This is a main issue in mobile robotics where the co-operation is the most useful. Indeed, to plan trajectory and to reach a goal, the robot must know where it is. The difficulty is increased by the characteristics of the low cost perception system composed of an odometry and a ring of ultrasonic sensors. Odometry is well known for the systematic error which increases with the distance. Ultrasonic sensors present several measure problems, specularity, multiple echoes and large solid angle. So, the algorithms are robust to erroneous measures and stay under human control to manage difficult situations which can not be solved automatically.

Localisation principle

The localisation is built following three ideas : i) the localisation must be as autonomous as possible considering the poor perception means, ii) the complexity of the system is reduced thanks to the use of the human capacities in the perception and decision fields to make a diagnosis or to treat a failure, iii) the person made the diagnosis by using three information types of information, exteroceptive and proprioceptive data and algorithm indicators.
The exteroceptive data are the ultrasonic measures which give the distance between the robot and environment elements (wall, corner, obstacle). The proprioceptive information is the location and the orientation of the robot in the flat computed from the odometry. The indicators inform the person about the behaviour of the localisation algorithms.
The main problem is that those three types of information are not completely reliable. To ensure a high low localisation performance rate and to avoid the rejection of the assistance system by the disabled people we propose a complex man-machine co-operation which can be divide into three levels. In the first level the robot automatically computes its situation during a move in the by fusing ultrasonic data with odometry flat (localisation on-line). If the person detects a problem he runs the second level(localisation off-line). The robot interrupts the mission to determine its situation by matching a great number of ultrasonic measures with the geometrical model of the environment. If the automatic localisation fails the operator takes charge of the failure management.

On-line localisation

The odometry is corrected on line - the robot is moving towards a goal - by ultrasonic measures. The robot is not lost but inaccurately localised. Few ultrasonic measure limit odometrical systematic errors up to a defined level. In every command modes the automatic process is under the control of the person. In our case the robot is a two driving wheeled circular structure. The perception system integrates a ring of eight Polaroid® ultrasonic sensors and an odometrical device.

The algorithm uses the ultrasonic measures to control the dead reckoning localisation. The main steps of this algorithm are:

1- Computing the robot location roughly by odometry
2- Matching few ultrasonic measures with elements of the modelled environment, here segments.
3 - Correcting the odometrical location by minimising the position and orientation differences between modelled and measured segments.

Complete results are published in [Hoppenot98].

Generally the knowledge of the position and the orientation of a mobile robot uses two functions called relative localisation and absolute localisation. The former is checked up by the odometry, simple and inexpensive. Its disadvantage is an unbounded accumulation of errors. The latter requires a more complex system based on a laser range finder or/and camera(s) to correct the odometry from time to time.
With a poor perception system, strategy must be different and must take into account the categories of odometrical errors ([Borenstein96]). In our approach, a real time algorithm limits systematic error accumulation with a low set of ultrasonic measures. The absolute localisation is no more necessary except if a non systematic error or if a bad knowledge of the orientation and the position of the robot at the starting point of the task occurs. In that case, a more complex procedure based on a large set of ultrasonic measures is run after the person has made the decision.

Off-line localisation

If, in spite of the on-line localisation, the robot is lost, an off-line localisation process is used. In that case, odometry can not be used. So, the localisation is only based on the ultrasonic measures and a priori knowledge of the environment (unknown obstacles can be present in the environment). To palliate the missing odometry an ultrasonic scanning is performed.
The position is calculated in three steps. The pre-processing step consists in merging measures to build

segments. The second step makes the assumption that the room is rectangular. The computed segments are merged to build rectangles that are matched with the known environment. At that stage, several positions of the robot are possible. The last step chooses the best solution. First, a cost function reduces to two the number of solutions (symmetry of the rectangle). The ambiguity is solved thanks to the door used as discriminating element. Exhaustive results are given in [Hoppenot00].

Error detection

As seen above the robot localisation with a poor perception system succeeds in most situations. Nevertheless the decision making « the robot is lost » and then « run off-line localisation » must be taken either by the robot or the disabled person. It is important in this kind of applications to think about man's mission. [Cunin97] insists on the active participation of the disabled people to the mission. Though the problem solving process must operate as autonomously and automatically as possible the user must interact at any time. In our opinion the man-machine co-operation allows to complete man or machine deficiencies : action for the disabled person and perception abilities and computing power for the robot due to low-cost constraints.

In the case of the robot localisation the person takes the decision « the robot is lost ». Before finding strategies of interaction, the pre-condition of the co-operation is to define the contents of the exchanged information and especially the information feedback to the man. This first work focuses on the ability of the person to determine if the mission is performing correctly without the help of the video image. When the robot is moving, two kinds of errors can occur : the localisation error in the flat and the blocking-up error defined as the incapability of getting out of a blocking situation .

The study is composed of two steps :

- the robot ability to detect errors thanks to available on-vehicle data (called automatic detection),
- the human ability to detect errors with only exteroceptive and proprioceptive information.

Automatic detection of errors

As seen before the available information is of three types:

- proprioceptive data (the robot speed and position variations);
- exteroceptive data (ultrasonic measures);
- indicator of the well operating of the on-line localisation algorithm (number of matchings between the measures and the environment).

Two criteria are defined, one for each kind of error. The first one, used for the position error, proceeds from the on-line localisation algorithm. The number of matchings between the measures and the environment is used to evaluate the relevance of the calculated position. A threshold is defined below which a position error is detected. Its value is 15% matched measures ; it takes into account the well-known problem of multiple bounds and cone aperture of ultrasonic sensors and the fact that the environment is not completely known.

The second one, used for the blocking-up error, proceeds from the knowledge of the speed and the position variation of the robot on the one hand and the sensors measurements and the other hand. If the robot does not go ahead any more (that means the linear speed and the position variation equal zero) the robot might be blocked. The second idea is to consider the measures of the sensors ; if they are small in all the directions (right, front and left), the robot might be blocked too. In fact, only the first condition is interesting. If the linear speed of robot equals zero for the last ten iterations, the robot is declared blocked if it has not reached the goal of its mission.

Using those criteria, only 1 false error detection is made on 18 tests. In the example giving the wrong detection, there is an obstacle in the middle of the room. Numerous ultrasonic measures come from the obstacle and not from the known environment. So, in spite of the good position of the robot, the matching percentage is not sufficient and an error is detected.

The main problem is to distinguish between the two types of errors. Indeed, a blocking-up error induces a position error due to the blind zone of the ultrasonic sensors.

Human detection of errors

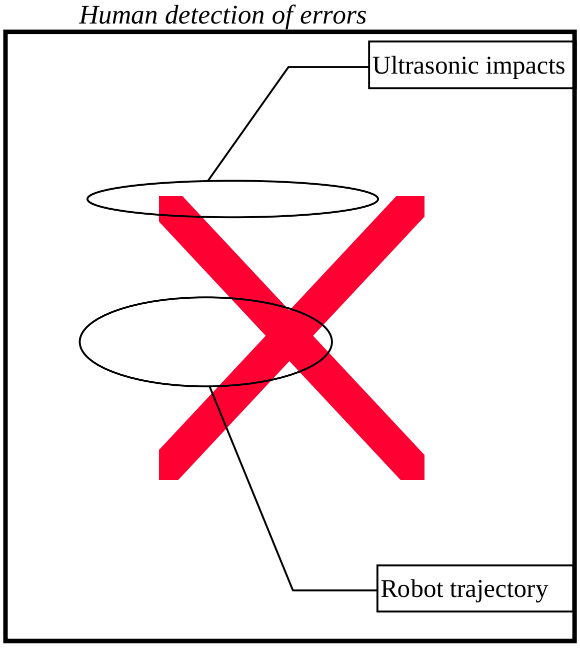


Figure 5 : *Training screen.*

Several experiments have been performed to see if a human operator is able to detect errors with only two kinds of information : the robot position given by the odometer and the ultrasonic measures.

The room is presented to the operator on a video screen (fig.9). Information feedback is added on the screen. Several cases are proposed : 4 information feedback combinations and 3 types of trajectories.

The 4 information feedback combinations are :

1 - only the present position without the sensors measures,
2 - all the positions since the beginning of the mission without the sensors measures,
3 - only the present position with the sensor measures,
4 - all the positions since the beginning of the mission with the sensors measures.

The three kinds of trajectories are :

1 - with a position error,
2 - with an odometrical error,
3 - without error.

Among the three groups (one per trajectory) of nine real trajectories, one is used to train the person.

Three sets of tests have been performed. Set 1 follows the previous protocol, set 2 is as set 1 but with a simplified feedback and set 3 is as set 2 but with a time constraint for the task execution.

In set number 1, there is no significant difference between disabled (here specially myopathes) and able people. More, the representation of the ultrasonic measures on the screen is too difficult to understand. Indeed each measure of the sensors was represented by a letter and a colour. In the following those impacts of the measures are pictured only with crosses and three colours for right, front and left impacts.

In set number 2, experts in robotics and ultrasonic technology have better results than unexperimented people. That means the latter one can improve the detection ability.

A complete feedback information (combination 4) gives the best result of detection.

The last set (number 3) is performed only with the combination 4 but under a time constraint : find the error as quick as possible. This forces people to use sensor measures to determine if there is an error or not.

Table 2 shows a comparison between set 2 and set 3. Column A reveals that the detection of non-error is better in set 2. The reason is that people waited for the end of the mission to see if the robot performed it well. But Column B indicates that the correct detection of error is better in set 3 ; moreover, all the localisation errors are correctly detected. That is very interesting in the field of disabled people assistance in which a non-detection of an error could be dangerous.

Column C shows that set 3 gives better results in the detection of the type of error too. The way to correct the position error might be different with an odometrical error than with a position one.

	A	B	C
Set 2	97%	77%	50%
Set 3	70%	100%	83%

Table 2: *Comparison between second and third tests.*

with : A : correct detection of non-error,
B : correct detection of error,
C : correct identification of error type.

Those tests reveal that disabled people, specially myopathes, have the same detection rate than able people. That is not very surprising : they only have physical handicap. The most important result is that, in spite of its complexity, the full information (position memory and ultrasonic measures) is useful and well suited to detect position errors. There is no error in the detection of errors which guaranties a great level of security.

Discussion

The previous paragraph presents two ways to detect errors, automatic and human detection. It shows that sensor measures and the matching number are pertinent to detect a position error. The issue is now to find the strategies to build the best co-operation. The problem consists in taking the decision to activate the off-line localisation procedure that delays the task in progress. At present time, an evaluation of the following strategy is in progress. While the robot moves the person judges if it is well-localised thanks to information feedback : sensor measures and the matching number. The decision of the running off-line localisation is taken by the person.

One idea is to use the automatic detection of error as a warning signal. Without detection, the person knows that there is no error (detection threshold can be adjusted). In the case of automatic detection, the supervisor is called to decide if the robot is lost or not. That is a good way to shift a responsibility to the machine when it is sure it works well.

CONCLUSION AND FURTHER WORK

Assistance robotics for disabled people can be emerged under two conditions: the person had to be integrated to the assistance process and the system must not cost too much. The low cost constraint limits the complexity system to the detriment of its autonomy ability. A well adapted co-operation between the man and the machine compensates the deficiencies of each one. From the person viewpoint, the robot appears as a tool able to act on the environment. The person adds the robot high level perception and decision means. The task allocation depends on the mission to perform. For planification and overall navigation the interaction of the person evolves following the command modes. In mode 2 the robot becomes transparent, the person pilots the pan and tilt camera inside the flat as though he was physically in the distant room.

Localisation is a most difficult problem when the perception system is poor. We are developing a three levels localisation. Autonomous on-line and off-line localisation are under the supervision of the person. We have studied the person ability to make a diagnosis only with exteroceptive and proprioceptive information without a video camera. The feedback to the operator can be completed by an indicator of the well operating of the on-line algorithm.

We are currently developing the man machine interface based on the enhanced reality.

BIBLIOGRAPHY

[Benreguieg97] M. Benreguieg, P. Hoppenot, H. Maaref, E. Colle, C. Barret : « Fuzzy navigation strategy : Application to two distinct autonomous mobile robots » - Robotica 1997, vol. 15, pp 609-615.

[Borenstein96] Borenstein J. : « Measurement and correction of systematic odometry errors in mobile robots » - IEEE Trans on Rob and Auto, vol. 12, N°6, dec 1996, pp869-880.

[Casals93] A. Casals, R. Villa, D. Casals : « A soft assistance arm for tetraplegics » - 1st TIDE congress, April 1993, pp. 103-107.

[Crevits95] Crevits, Gandibleux, Millot : « The choice of a man-machine co-operartion » - 6th IFAC/IFIP/IFORS/IEA Symposium of analysis, design and evaluation man-machine systems, MIT, Cambridge, USA, 1995.

[Cunin97] J.C. Cunin : « Etat des besoins des personnes handicapées moteur » - Journée automatique et santé, CRLC Montpellier, 6 juin 1997.

[Dario95] P. Dario, E. Guglielmelli, B. Allotta : « Mobile robots aid the disabled » - Service Robot, vol. 1, n°1, pp 14-18, 1995.

[Fiorini97] P. Fiorini, K. Ali, H. Seraji : « Health Care Robotics : a Progress Report » - IEEE Int. Conf. On Robotics and Automation, Albuquerque, New Mexico, April 1997, pp. 1271-1276..

[Guglielmelli96] E. Guglielmelli, P. Dario, C. Laschi, R. Fontanelli : « Humans and technologies at home : from friendly appliances to robotic interfaces » - IEEE Int Workshop on Rob. and Human Com., 1996.

[Hoppenot98] P. Hoppenot, E. Colle : « Real-time localisation of a low-cost mobile robot with poor ultrasonic data » - IFAC journal, Control Engineering practice 1998, vol. 6, pp.925-934.

[Hoppenot00] P. Hoppenot, E. Colle and C. Barat : « Off line localisation of a mobile robot using ultrasonic measures » - Robotica, to be published, 2000..

[Jackson93] R. D. Jackson : « Robotics and its role in helping disabled people » - Engineerinf Science and Educational Journal, Dec. 1993.

[Kawamura93] K. Kawamura, M. Cambron, K. Fujiwara, J. Barile : « A cooperative robotic aid system » - Virtual Reality Systems, Teleoperation and Beyond Speech Recognition Conf., 1993.

[Kawamura94] K. Kawamura, M. Iskarous : « Trends in Service Robots for the Disabled and the Elderly » - Special session on Service Robots for the Disabled and Elderly People, 1994, pp. 1647-1654.

[Kawamura94b] K. Kawamura, S. Bagchi, M. Iskarous, R. T. Pack, A. Saad : « An intelligent robotic aid system for human services » - AIAA/NASA Conf. On Intelligent Robotics in Fields, Factory, Service and Space, March 1994, vol. 2, pp. 413-420.

[Neveryd95] H. Neveryd, G Bolmsjö : « WALKY, an ultrasonic navigating mobile robot for the disabled » - 2nd TIDE Congress, Paris, 1995, pp. 366-370.

[Topping98] M. Topping, J. Smith : « The development of Handy 1, a rehabilitation robotic system to assist the severely disabled » - Industrial Robot, Vol. 25, n°5, 1998, pp. 316-320.

[Vanderloos95] H.F. Van der Loos : « VA/Stanford Rehabilitation Robotics Researchand Development Program : Lessons Learned in the Application of Robotics Technology to the field of Rehabilitation » - IEEE Trans. on Rehabilitation Engineering, Vol. 3, n°1, march 1995, pp 46-55.

Command mode	**Planning**	**Navigation**	**Localisation**	
Mode 1	• Pointing out : man • Path planning : machine	• Supervision : man • Control/command : machine	• on-line : machine • supervision : man	• off-line : MMC
Mode 2	• Pointing out : man • Auto-tracking : machine	• Supervision : man • Control/command : machine	• on-line : machine • supervision : man *	• off-line : MMC
Mode 3	• Control/command : man	• Control/command : man (assisted by the machine)	• on-line : machine • supervision : man *	• off-line : MMC

1) MMC : Man Machine Co-operation

*2) * : the function can be disabled*

Table 1 : *Co-operation between man and machine.*