HUMAN-LIKE BEAVIOUR ROBOT - APPLICATION TO DISABLED PEOPLE ASSISTANCE

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ABSTRACT

In the field of rehabilitation robotics, mobile personal robot represents an attractive solution, even in economical terms, in comparison with desktop workstation. Assistance system ARPH is composed of manipulator arm mounted on a mobile robot. In order to avoid an increasing of complexity due to the need of system autonomy in a partially known environment, our approach is based on a close co-operation. The disable person and the system provide their skills and execute missions by task-sharing. The first condition for a good co-operation is that the person understands how the robot performs its task. It is made easier if the autonomous functions of the robot have human-like behaviours. The paper presents this approach for the main functions required for the robot displacement: planning, navigation and to a minor extend localisation. Man machine co-operation is evaluated by an experiment in which users control the mobile robot during a "go to the target " mission.

Key words: Human-like behaviour robot, disabled people assistance, Man-Machine Co-operation.

INTRODUCTION

Today's life difficulties of disabled people are more and more taken into account for accessibility, integration into the job market, medical assistance… The primary objective of rehabilitation robotics has been to fully or partly restore the disabled user's manipulative function by placing a robot arm between the user and the environment. Assistance system currently available on the market require heavy adaptation of the house by means of special building design. On the contrary, mobile robots represent an attractive solution as they could minimise the required degree of adaptation of the house. The success of rehabilitation robotics depends on the respect of two key conditions. The first one is the cost of the assistance. It seems important to admit the system cannot be completely autonomous for the robot has limited perception and computing means. In that case, man-machine co-operation permits to balance machine deficiencies by the perception, the decision, and to a minor extent the action means of the person.

The second condition concerns the very principle of aid. The system must not "do for" but compensate the action deficiency of disabled people ([Cunin97]). Disabled person has to participate in the task performed by the system., that also implies man-machine co-operation. The person intervention degree during the task progress is variable. It can begin by taking part in perception or decision functions until a remote control of the system. The partial autonomy of the system completes the field of person abilities either to palliate deficiency due to the handicap or to realise tedious actions.

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 object position is not known. This allows more flexibility but needs sensors for 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]).

The project presented is developed with AFM (French Association against Myopathies). It belongs to the "Mobile robot system" described above. A manipulator arm is mounted on a mobile robot. The mission consists in carrying and manipulating an object in a partially known environment such as a flat. The flat plan is known but table, chairs are not modelled and are considered as obstacles. The first section describes the assistance system and the three main control modes. The second section tackles the human machine co-operation focusing on the interpretation of robot behaviour by users. In order to make co-operation easier people must understand the robot behaviour while a mission is in progress, especially for control modes that share tasks between both user and system. The user's interpretation of the way the robot operates will be natural if robot functions copy human behaviours. The idea is applied to the three functions needed for the displacement of the robot: planning, navigation and localisation. The third section presents a realistic experiment. Eleven people have to control the mobile robot to an object located in a flat composed of two rooms. The experiment objective is to evaluated the learning easiness and the complementarity of control modes.

ASSISTANCE SYSTEM ARCHITECTURE

ARPH (Assistance Robotics to Handicaped Person) system is composed of a control station and a manipulator arm mounted on a mobile robot (Figure 1). The problem is divided into two steps: move to the target and object manipulation.

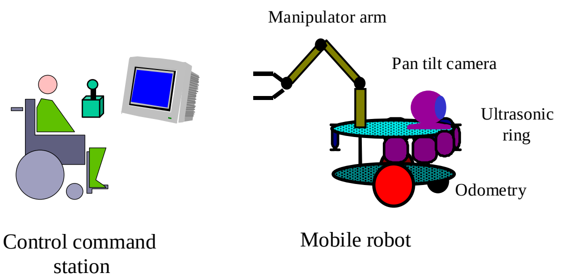


Figure 1 : *System architecture.*

Mobile robot

In order to "not cost too much" the robot has limited and poor perception means, 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 ultrasonic technology is limited to proximetry because of poor measurement characteristics and a high rate of erroneous measures. 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. It presents a smart feature: the auto-tracking mode. Camera automatically follows the movement of an object. Camera plays two roles: i) a perception device which provides video feedback during the robot displacement, ii) a command device which provides robot the direction to follow or the object to reach or follow (auto-tracking mode of the camera).

Control-command station

The Control station is composed of :

i) control devices well adapted to the handicap of the disabled person

ii) a screen which displays different types of information via enhanced reality techniques (Figure 2) such as video image of what is seen by the robot, virtual aids superimposed onto the video image, robot position on a 2D flat plan, robot operating indicators,...

Control Modes

Three main modes allow the control of the robot displacement. In mode 1, the person points out the

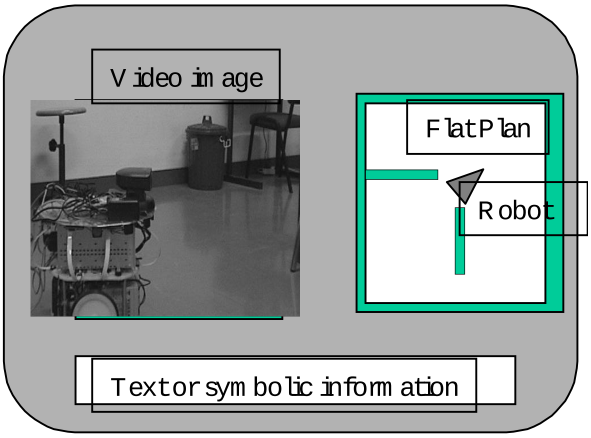


Figure 2 : *Enhanced reality approach for the feedback information.*

destination on a 2D flat plan displayed on a screen. The robot automatically reaches the destination avoiding obstacles. In mode 2 the person points out a direction or an interesting object on the video image provided by the camera. The user defines the goal driving the tilt and pan base of the camera. The auto-tracking function of the camera is used to pilot the robot to the goal. In mode 3 the person teleoperates the robot "manually" via a joystick or any control device. An assistance to avoid obstacles automatically may be available.

ROBOT HUMAN-LIKE BEHAVIOURS

A displacement of a mobile robot requires three functions: planning, navigation and localisation. Planning determines the best path to go from one point to another. Navigation ensures the robot follows the planned path avoiding obstacles. Localisation gives the position and the orientation of the robot in the flat at any time. The description of control modes has shown that some tasks can be performed by using both different skills of user and robot. It is important the person understands the robot behaviours in those cases. A natural approach is to give human-like behaviours to robot functions needed for the robot move.

Planning

The problem is to reach a goal. A person uses different strategies of planning. For a far destination a plan is used to find a way to go from one point to another. If the destination is within sight the person reaches the interest point following the direction he looks at.

In our application the system has the same human behaviours. In a classical robotic approach the robot computes a path through the flat to reach the goal the known flat plan ([Benreguieg97]).

The second way to plan a trajectory is to use the camera in auto tracking mode. The person points out a goal with the camera. The goal must be within sight of the camera. The camera tracks the object automatically. The robot moves in the direction pointed out by the camera. This is a human like behaviour. The object is considered as a target which can be mobile. The remaining issue is only to avoid obstacles on the path. This is a navigation problem.

Navigation

The problem is to follow the planned trajectory. A person divides navigation into two behaviours: goal-seeking and obstacle avoidance. A fusion of the two behaviours is performed during the displacement. The orientation of the head defines the direction for goal seeking. If an obstacle is on the way, the trajectory is deviated locally to avoid it. Usually people try to walk as far as possible from obstacles, for example in the middle of corridors.

Automatic navigation imitates the human behaviour making the fusion of goal-seeking and obstacle avoidance. For goal-seeking the direction is defined by the relative positions of robot and goal. If a non modelled obstacle stands on the robot path, it must be avoided. Ultrasonic sensors detect these obstacles and fuzzy logic manages the obstacle avoidance. As human like behaviour the robot goes in the middle of the free space. The fuzzy controller is based on a set of rules such as :

R_i " **If** R_n is x_i **and** L_n is y_i **Then** $C_{\omega a}$ is t_i **and if** F_n is z_i **then** C_{va} is u_i " .

Else

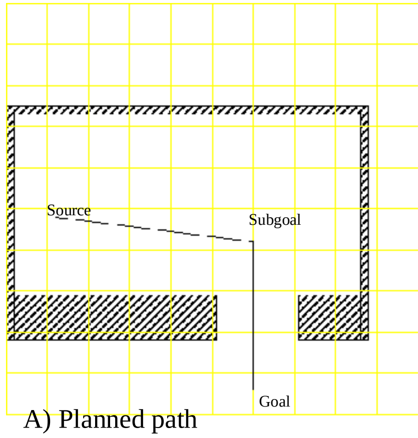
R_{i+1} " **If**... "

x_i, y_i, z_i, t_i and u_i are linguistic labels of a fuzzy partition of respectively the universes of discourse of the input R_n, L_n and Fn and the outputs $C_{\omega a}$ and C_{va}. The inputs variables are respectively the normalised measured distances on the right *R*, on the left *L* and in front F such as :

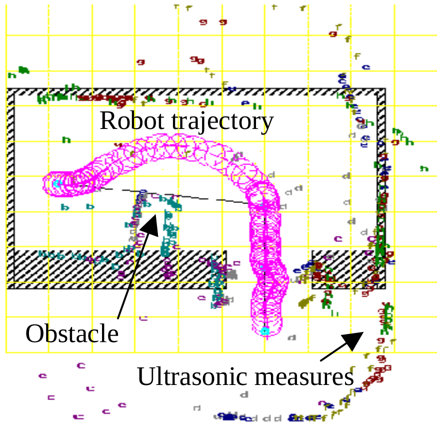
$$R_n = \frac{R}{R+L},\ L_n = \frac{L}{R+L} \text{ and } \begin{cases} \text{if } F < \sigma \text{ then } F_n = \frac{F}{\sigma} \\ else\ Fn = 1 \end{cases}$$

where σ defines the influence distance for obstacle avoidance. Thanks to this normalisation, the universe of discourse adjust to the sensors range meaning that the robot stays as far as possible from the 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. Figure 4 shows a trajectory followed by the robot with a non modelled obstacle in the room. All these results are detailed in [Hoppenot96].



A) Planned path



B) Robot navigation with obstacle avoiding

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

Localisation

The cost effective constraint due to the field of application implies the use of a poor perception system as seen before. Three levels of behaviour are used in the localisation function. They are well suited to the different situations encountered. Each level uses specific algorithms, little sensitive to the high rate of wrong measurements and to the presence of obstacles (by definition not modelled).

In the first level, the robot knows approximately its position and orientation. They are updated on-line by the odometer under the control of the ultrasonic sensors. When the robot notice it is lost (the decision can be taken in collaboration with the human operator), the off-line localisation level is activated. The third behaviour level corresponds to the human intervention. The supervisor analyses the situation thanks to two kinds of information: sensor measurements displayed on a 2D plan of the environment and an indicator of the quality of the position given by the algorithm running on the mobile base.

On-line localisation system is completely presented in [Hoppenot98]. Off-line localisation uses human like behaviour techniques. The problem is to find the robot position in a partially known environment. Dead-reckoning system (odometry) is wrong and provides erroneous data. In that case, the off-line localisation aims at initialising odometry correctly. Only ultrasonic measures are available. As people lost in a town, the robot looks for landmarks in the room. If some landmarks are recognised and with the help of the flat plan, the robot is able to compute its location. The main problem is the land mark recognition. Two kinds of landmark are interesting in an indoor environment: walls and doors. Walls are detected with classical techniques (ultrasonic image segmentation). Door detection is a typical pattern recognition problem. Literature proposes several approaches to solve the classification problem particularly neural networks and statistical methods. It depends on the application constraints and on the a priori knowledge on the input data and physical phenomena. Neural networks are more effective and economic than the statistical methods when natural data are not describable by low-order statistical parameters, their distribution are non-Gaussian, their statistic are non stationary and the functional relations between natural data elements are non-linear ([Kohonen97]). The results, detailed in [robotica], shows the efficiency of Neural Networks methods in comparison with two statistical ones, Linear Discriminant Analysis, Quadratic Discriminant Analysis.

EXPERIMENTAL RESULTS

Experiments have been realised to evaluate the three command modes in real conditions. Two points are studied: i) does the user come up against difficulties while he uses the different modes? ii) Is there any interest the three modes are complementary for the realisation of a mission?

Experiment description

The environment is a two room flat. Human operator is in front of the control station in the first room (3x2 m). The most important part of the second room (3x3 m) is out of the direct sight of the person. That distinguishes two situations within and out of sight.

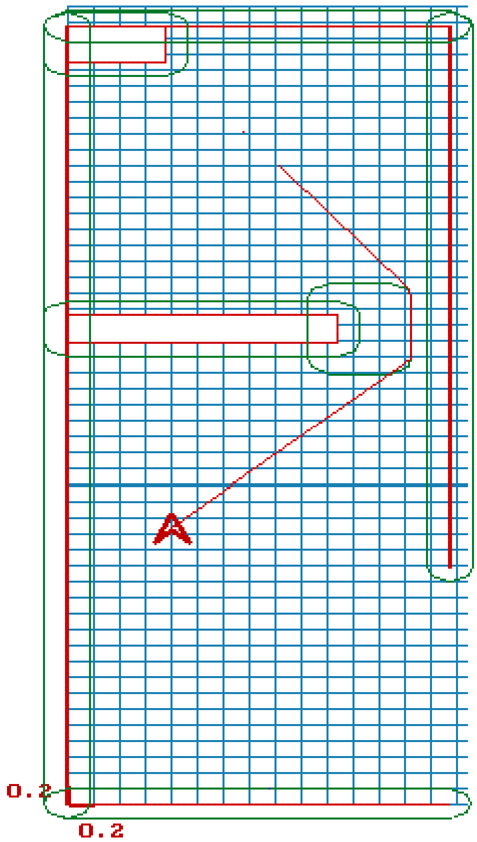


Figure 5 : *Experimental environment.*

Man machine interface

The experiment focuses on co-operation so a very simple man machine interface has been developed. It allows the command of the robot and the camera by means of a mouse and keyboard arrows. The information feedback interface displays the modelled environment and the robot position (Figure 5) on a screen and the camera image on another screen. Following modes, some information are added, for example the planned trajectory by a succession of segments, the robot location by a triangle or ultrasonic measure by a little cross.

Control modes

As seen in a previous section, three command modes are available to control the robot displacement :

i) In Mode 1, called automatic mode, the human operator defines the goal on the flat plan drawn on the screen. The robot reaches the goal autonomously.

ii) In mode 2, called mixed mode, the human operator points out an object with the camera. The robot follow the direction given by the camera, avoiding automatically the obstacles.

iii) In mode 3, called manual mode, the user remote controls the robot.

Experimental procedure

The mission consists to reach a visible or not visible object in the flat. The mission allows the evaluation of the co-operation during planning and navigation. In order to study the case of localisation, sometimes the starting position of the robot is wrong.

Finally, four cases are possible:

1-Visible object, good initial position
2-Visible object, wrong initial position
3-Invisible object, good initial position
4-Invisible object, wrong initial position

11 subjects, all students in technology, have been tested in two sessions. The first session begins with a learning period. Then, a set of 4 tests (one of each case) has been realised. Free interview has been made for the person to give first impression. The second session was composed of 12 tests (three sets of each case). A directive interview has been made after them.

Hypothesis

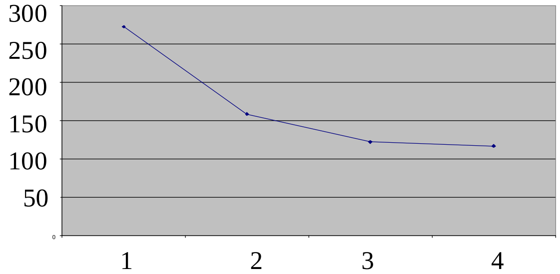
Hypothesis 1: a correct understanding of robot behaviour by the user makes easier the system learning.

Hypothesis 2: following situations, user develops strategies that combine several control modes. The fact that modes are complementary encourage that inclination.

Hypothesis 3: in case of unforeseen events, human operator is able to modify the strategy. In the experiment, the unexpected event will be a wrong initial position of the robot.

Results

Figure 6 gives the average time for the execution of a mission according to sets of 4 tests.

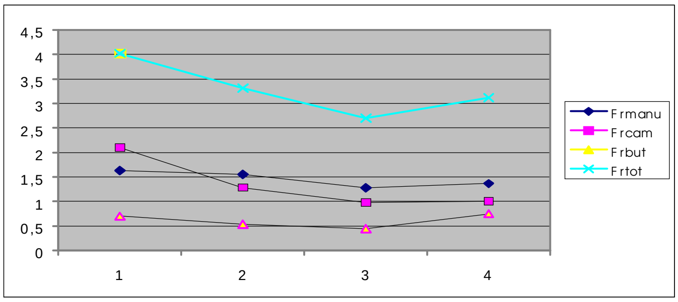


(y axis : ms, x axis : number of 4-test sets)

Figure 6 : *Average time for the execution of a mission*

The stabilisation of time performances from the third train proves a quick learning.

Figure 7 illustrates the change number of control modes during a mission according to trains of 4 tests.



(y axis : ms, x axis : number of 4-test sets)

Figure 7 : *Change number of control modes*

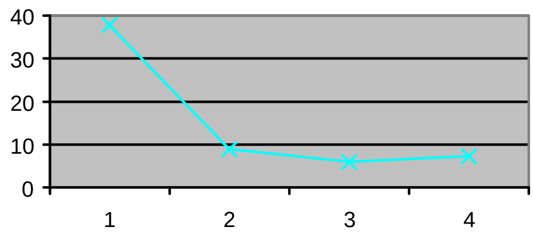
Subjects use a combination of 3 modes. A same mode can be used several times. Statistically there is a high correlation between the use of manual mode and either mode 2 (r= 0.23 ; p< 0.002) or mode 1 (r= 0.71 ; p <0.001). This is not true between mode 1 and mode 3.

	Mode 3	Mode 2	Mode 1
Invisible Object	39%	48%	13%
Visible Object	41%	42%	16%

Table 1 : Utilisation percentage of the different modes.

When the object is not visible subjects adapt the strategy a little; the mode 2, using the camera for the control, seems more used (table 1)

Figure 8 shows that the utilisation time of mode 2 when there is a position error according to trains of 4 tests.



(y axis : ms, x axis : number of 4-test sets)

Figure 8 : *Change number of control modes*

Subjects learn quickly not to use the automatic mode 1. Indeed this mode cannot operate correctly in that case but nobody warned subjects about operating limits of automatic mode intentionally. Therefore subjects succeed mission by changing the strategy.

Discussion

The quick system learning shows a good understanding of the way the robot moves in the environment. It is due to the human-like behaviour of the robot for a part.

Strategies are built as a combination of control modes. The fact the modes are complementary gives users total freedom to elaborate their own strategy. Human operator has integrated the working way of automatic modes (modes 1 and 2) but manual mode remains the central mode as indicated by the high correlation between manual mode and both automatic modes. The other modes are seen as assistance ones.
Subjects can be aware of the ineffectiveness of modes in special conditions. The different interviews of subjects show that a automatic mode must be reliable and its working limits known else the person is inclined to reject it even for situations it would be operated correctly in.

CONCLUSIONS

At term, ARPH system aims at restoring manipulative functions of disabled people. Assistance system is composed of a control-command station and a manipulator arm mounted on a mobile robot. The paper focuses on the displacement of the robot in an indoor environment. In order to respect the constraints "not do for " and "not cost too much" a very close co-operation between user and robot must be put in place.

Following control modes, a task execution can be shared by the person and the robot. For example, the person pilots the robot direction manually and at the same time the robot avoids obstacles. For a well-suited co-operation the user must understand the robot behaviour. The main functions: planning, navigation and localisation needed for the displacement of the robot, integrates human like behaviours. This approach makes the co-operation easier for the user.

Strategies developed by human operator to succeed a mission has been evaluated during an experiment The mission has consisted to reach an object into a 2-room flat.
Strategies are built as a combination of control modes. The fact the modes are complementary gives users total freedom to elaborate their own strategy. Human operator has integrated the working way of automatic modes (modes 1 and 2) but manual mode remains the central mode. The other modes are seen as assistance ones. People, disabled or not, wants to directly act as far as possible (manual mode) but do not refuse an assistance by more or less automatic modes.
An automatic mode must present a reliable working else the person is inclined to reject it. It is important to accurately learn the operator the way the mode operates and its limits.
Mode 2 use the camera both as control and feedback device copy a natural behaviour based on the usual human move. People look at an object and walk in that direction automatically.

be easy to understand and easy to operate. It is a natural mode, based on natural human displacement: eyes look in a direction and legs walk in that direction.. Mode 1 (completely automatic mode) is less used than the others because of the control slowness.

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