Mobile robot command by man-machine co-operation -

Application to disabled and elderly people assistance

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Abstract

Disabled people assistance is developing thanks to progress of new technologies. A manipulator arm mounted on a mobile robot can assist the disabled person for the partial restoration of the manipulative function. User pilots the robot via a control station using enhanced reality techniques. To be affordable such a system must be cost effective. That constraint limits perception means: ultrasonic ring, dead reckoning and low cost camera. The development of the project has followed two stages. The first one consists of giving maximum autonomy capacities to the robot for planning, navigation and localisation. The second stage is the study of the Man-Machine Co-operation (MMC) for the command of the robot system. Indeed, the aim is to perform a mission (mobile robot displacement) using robot capacities and man possibilities. Users build their own strategies to carry out successively a mission. Strategy can be seen as a succession of control modes, which can be manual, automatic or shared. In the latter case the control of the robot is shared between human operator and machine. The main problem is then task allocation between both intelligent entities. Each one has planification, navigation and localisation abilities. The paper presents our approach for planning and navigation and develops a more specific study about robot localisation.

Key words: Disabled people assistance, man-machine co-operation strategy, control modes, task allocation, mobile robotics.

1. Introduction

The emergence of robotic solutions in disabled people aid tasks is realistic if two conditions are respected. 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 [1]. 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 ([2]) and DeVAR ([3]) 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 ([4]) and ISAC ([5]). Other solutions are wheelchair-based systems. The most well known system is MANUS ([6]). Mobile robot systems are also used: WALKY ([7]), Health Care Robot ([8]), URMAD ([9]) and MOVAID ([10]). The last kind of systems proposed are collaborative robotic aid systems where multiple robots perform several tasks for the user ([11]).

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 of carrying 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 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 ([12]). 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 move 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 kinds of 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. Different planning strategies are considered in section 4 where the intervention of the person is variable. Section 5 is interested in the navigation which can be completely automatic, manual or manual assisted by some functions of the machine such as obstacle avoidance. Section 6 develops localisation, which requires the closest man machine co-operation because of the difficulty of the operation.

2. 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).

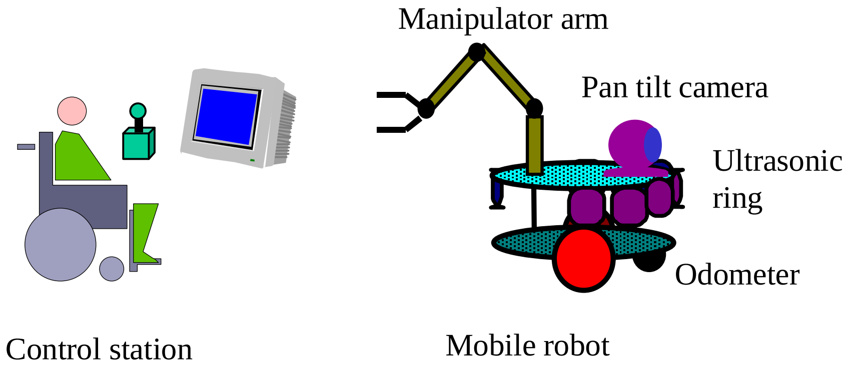

Figure 1: *System architecture.*

2.1 Mobile robot

ARPH (Figure 2) is fifty centimetres high. It is a half cylinder sixty centimetres in diameter. It is equipped with DX motors, one of the most used on the market of electrical wheelchair. This choice is driven by AFM (end user association). It makes the robot repairable by classical after sale services. The body is in fibreglass, which is not very expensive and easy to shape. A PC is embarked. Manus arm, which is already adapted for electrical wheelchairs, is used.

Figure 2*: ARPH (Assistance Robot to Person with Handicap).*

In order to not cost too much the robot has limited and poor perception means at its disposal, dead reckoning and ultrasonic ring. A camera is used as well. Dead reckoning gives the position and the orientation of the robot versus angular rotation of the wheels. The method is simple and low cost but presents two kinds of errors: systematic errors and non-systematic errors ([15]). Systematic errors come from robot modelling errors: wheel diameter and distance between wheels. They induce incremental computing errors, which are not bounded. With a 3% typical error, dead reckoning gives correct position of the robot for a small distance (less than 1 meter). So, it can be used locally. Non-systematic errors are mainly due to wheel spin and sliding. When it occurs, dead reckoning is not more usable.

Ultrasonic ring measures the distance between the robot and obstacles all around the robot. It is composed of eight Polaroid® ultrasonic sensors, one each 30° on the front of the robot and one on the back of the robot (Figure 3). With 30° aperture cone (Figure 3), they have medium metrology characteristics and a high rate of erroneous measures due to multiple bounds and specularity. So, generally, ultrasonic technology is limited to proximetry. Localisation algorithms must operate in those difficult conditions.

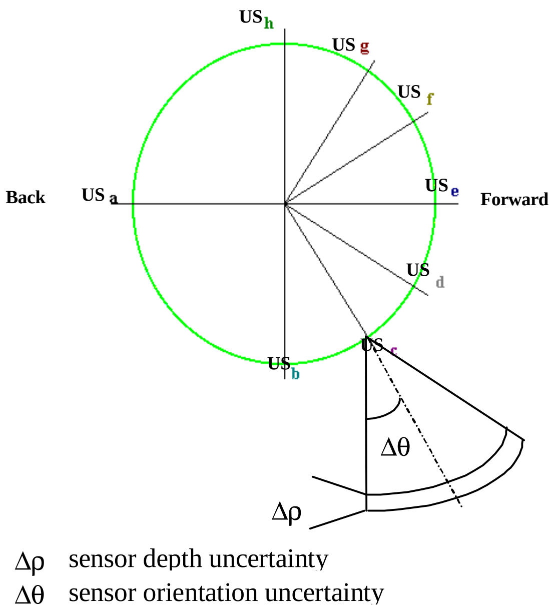

Figure 3: *Ultrasonic sensor layout.*The camera mounted on a pan and tilt base is a commercial device dedicated to general surveillance applications. It is used as a feedback sensor and control device thanks to a smart feature: the auto-tracking mode. The camera automatically follows the movement of a target.

2.2 Control station

The control station is composed of a screen, which displays different types of information via enhanced and virtual reality techniques (Figure 4). Three windows are dedicated to feedback information. On the top left, a video image of what is seen by the robot is shown. On the top right, a virtual camera shows the robot position on the 2D flat plan. On the bottom left, another virtual camera shows a virtual image corresponding to the real image given by the camera on the top left. Comparison of the two images gives information on the localisation of the robot. On the bottom right complementary feedback information is given such as robot operating indicators. A control panel offers the operator the possibility to pilot the robot by clicking on mouse buttons. The robot control can be performed with a keyboard with a force feedback joystick too.

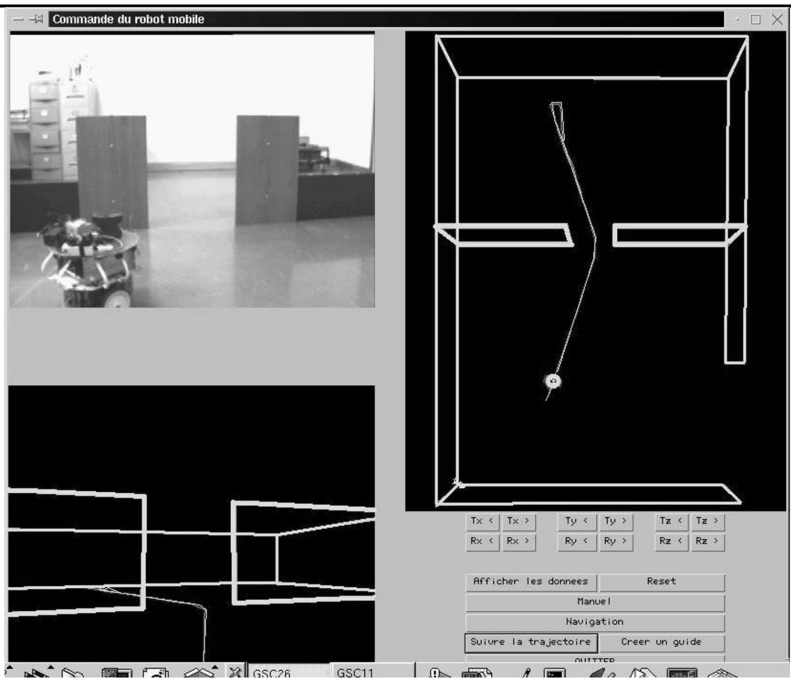

Figure 4: *Enhanced reality approach for the feedback information.*

One main characteristic of the man-machine interface is to be flexible. It must adapt to different persons with different handicaps. All feedback information and control devices are proposed to the person who can choose which one is well adapted. This choice can evolve depending on training but either the tendency to get tired or the changes of machine performances.

3. Task allocation

As seen in introduction the mission "move the robot from one point to another" implies three main functions: planning, navigation and localisation. Man and machine have capacities, perception decision and action, to perform them. The main question is to share tasks to be achieved between man and machine. Three kinds of command modes exist on the robot. Firstly an automatic mode gives the operator the possibility to only design a goal and ask the robot to reach it by itself. The operator plays a supervision role while the robot computes planning, navigation and localisation tasks. On the opposite, the operator can pilot directly the robot. Using only these two modes, man and machine operate separately from each other. A third kind of modes exists, which shared tasks to be realised between man and machine. That sets a real co-operation.

A lot of shared modes can be defined. Three of them have been implanted on the robot yet. The first one consists of helping the operator to drive the robot with obstacle avoidance (see navigation section). The second one uses the camera as a control device. With the auto-tracking system, an object is design to the robot (see planning section). Then the robot can reach it automatically (see navigation section). The third shared mode uses the camera too. But in that case, the operator pilots directly the camera and the robot follows its movement (see planning section). These two last modes are human-like ones: a person generally walks in the direction of the gaze. All the modes are more precisely described in the following sections.

Missions can be divided into basic actions called operations. For example: choose a goal or a trajectory, avoid an obstacle, reach a goal… Operations are realised using control modes presented above. A sequence of control modes is called a strategy. Two questions must be asked. Firstly, does a strategy exist for all missions? In other words, is it possible to realise every mission? Experiments performed in the lab (see following sections) show that operators can reach many goals using different control modes. Proposed control modes are complementary. A second question must be asked: is the strategy developed in one situation unique? The brief description of the control modes shows that different tasks (planning, navigation and localisation) can be performed by different modes. The proposed control modes are redundant. This is why operators can develop strategies by choosing which sequence of modes can be applied to reach the goal.

Columns of Figure 5 present examples of task allocation. Right column represents the totally manual mode. Left column represents the totally automatic mode. The development of a strategy consists of choosing at least one cell of each row. In [12], task allocation is divided into two families. Static allocation consists of defining who is in charge of a task for all missions. The allocation is decided off line. The process works easily but this solution is very static. The second family is dynamic allocation. The responsible of a task is chosen on line depending on the situation. If the machine makes the choice it is called implicit dynamic allocation and if the human operator makes the choice it is called explicit dynamic allocation. In the case of disabled people assistance, static allocation can be useful for severely disabled people. Most of the tasks can be realised automatically. But in most of cases, dynamic allocation is more suitable. It gives flexibility to drive the robot. As disabled people want to act, explicit dynamic allocation is interesting. But machine can help for choosing modes. That is what we call assisted explicit dynamic allocation.

Rows of Figure 5 present different modes for each task. The three tasks classically proposed in robotics are described in the following sections. Goal designation is added to the three previous ones because of the field of application. The human supervisor chooses the aim of a mission. But because he/she is disabled, the choice can be at different abstraction level. The gaol can be design on line by the user in manual mode (Figure 5, right column). It can also be pointed using the camera. If the object moves, the camera follows the movement without human intervention. The goal can be pointed out on the flat plan. Higher semantic information can be used by designing the fridge or the television. Auto-search is the highest semantic designation. The robot can be asked to bring back a red book. In that case, it must define a complex strategy to find the book and then to bring it back.

To make mode change possible, human operator must understand behaviours of the robot in automatic modes ([12]). Localisation is divided into three levels: on-line localisation, off-line localisation and error detection. Human beings follow the same strategy when they walk in the street: they follow the street (on-line localisation) until they are lost (error detection). Then, they look at a map and search a street name to find their present position. In navigation task the operator supervises the mission. He/she must understand why the robot follows the trajectory drawn on the screen. Automatic navigation is based on the fusion of two behaviours, goal seeking and obstacle avoidance. This is the strategy followed by human being who looks at an object to reach and avoids obstacles between the object and his/her position. More details are given in navigation section. About planning, the trajectory computed by the robot to go from one point to another must seem logical to the supervisor. The algorithm finds the smallest distance between the two points, which is a natural criterion for human being looking for a trajectory to reach a goal. More details are given in planning section. Automatic goal designation is not detailed in this paper.

<table>
<tr><th>Function</th><th colspan="4">Different possibilities of control</th></tr>
<tr><td>Goal designation</td><td>Auto-search for object</td><td>User points the goal out on the flat plan</td><td rowspan="3">User remote controls the robot direction via the camera (with or without automatic obstacle avoiding)</td><td>User</td></tr>
<tr><td>Planning</td><td colspan="2">Automatic</td><td>User</td></tr>
<tr><td>Navigation</td><td colspan="2">Automatic</td><td>User (with or without obstacle avoiding)</td></tr>
<tr><td>Localization</td><td>Automatic</td><td colspan="2">Automatic or
By a man- machine co-operation</td><td>User</td></tr>
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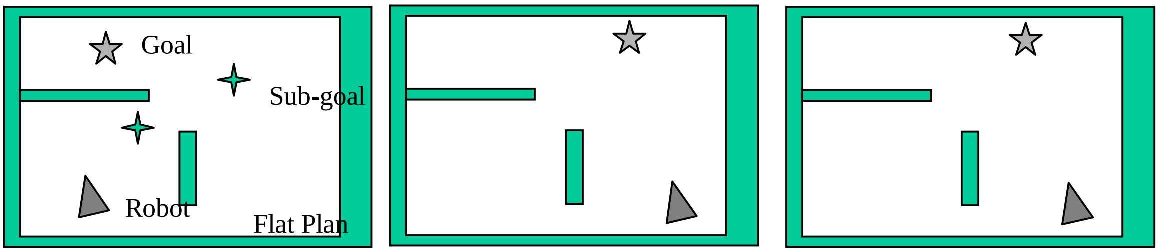
Figure 5: *Example of task allocation.*

4. Planning

After goal designation that is only suggested in this paper, planning is the first step to execute a mission. Man and machine have capacities to determine the way to follow in the flat. In all modes defined above, the person gives the goal (Figure 6).



Automatic mode: the person defines the goal on the flat plan.

Shared modes: the person defines the goal on the video image. The camera uses the auto-tracking function.

Manual mode: the person teleoperates the robot. The camera is used only for feedback.

Figure 6: *Path planning following the command mode.*

Automatic mode

In automatic mode, planning method is based on visibility graph and A* algorithm ([13]). Visibility graph is a list of all the trajectories that the robot can follow. It is obtained by joining all the vertices of all the objects of the known environment with a straight line if it does not intersect any obstacle (Figure 7). When all the possible trajectories are computed, one of them must be chosen. A* algorithm selects the optimal one by minimising a cost function. The criterion used is the distance but it is also possible to penalise some segments taking into account other criteria: difficulty to localise the robot, difficulty to drive the robot in cluttered environment… It is also possible for the person to give some subgoals before computing.

Human being develops similar strategies. With a map of a town (knowledge of the environment), it is possible to find different ways to go from one point to another. The optimal one is chosen taking into account car traffic, traffic lights, one-way streets…

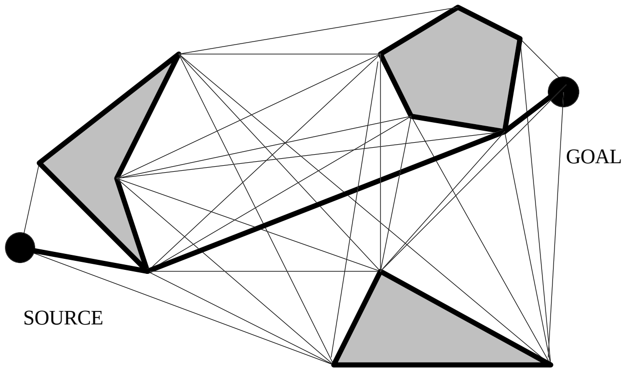


Figure 7: *Optimal path computed with visibility graph and A* algorithm.*

Shared modes

In shared modes, the person points out a goal with a camera. The goal must be in the vision field of the camera. Two possibilities exist to pilot the camera: manual or automatic tracking. In manual tracking, the operator drives directly the camera in the direction he/she wants. In automatic tracking, the operator chooses an object by pointing it with the camera. The camera tracks the object and automatically points out on it with pan and tilt moves. In both cases, 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. Human being develops similar strategies when he/she goes from one point to another. The orientation of eyesight gives the direction of the movement. The remaining issue is only to avoid obstacles on the path. This is a navigation problem.

Manual modes

In manual mode, planning is performed on line by the person who drives manually the robot. The camera is then used only to return visual information.
Human being develops similar strategies when he/she looks for his/her way. The choice of the path to follow is performed on line during motion taking into account information coming from the environment.

5. 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 move orders to the robot. That is what is done by human being. When a person wants to go and catch an object, he/she looks at it and follows the direction given by the eyesight. If there is an obstacle on the way, he/she detects it and avoids it.

For the robot, entirely automatic navigation can be performed. A force, inversely proportional to the distance, attracts the robot. Angular speed and the linear speed are computed. Angular speed AS is proportional to the robot direction and the direction between the robot and the goal. It is also inversely proportional to the distance between the goal and the robot. As it is difficult to turn quickly and to go straight quickly as well, linear speed LS is defined as follows: LS = 1 - |AS| (AS is normalised).

If an unmodelled obstacle stands on the robot planned path, it must be avoided. Ultrasonic sensors detect the obstacles. Fuzzy logic function manages the obstacle avoidance. It consists of reaching the middle of the collision-free space (Figure 8). Measure distances L, R and F are normalised as follows:

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

It is based on rules such that:

- "If the distance on the left is small (S) and the distance on the right is big (B) then turn slowly on the right (NS)"
- "If the distance on the left is medium (M) and the distance on the right is medium (M) then do not turn (Z)".

Five linguistic labels are defined for the distance: Zero (Z), Small (S), Medium (M), Big (B) and Very Big (VB). Five linguistic labels are defined for the angular speed: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB) (negative is right direction, positive left direction).

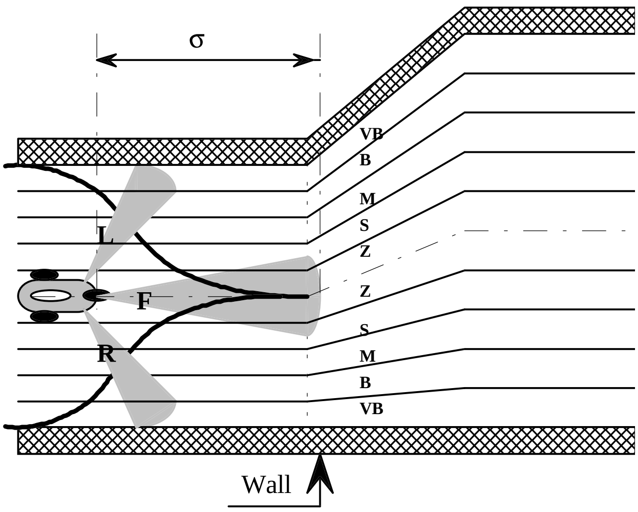
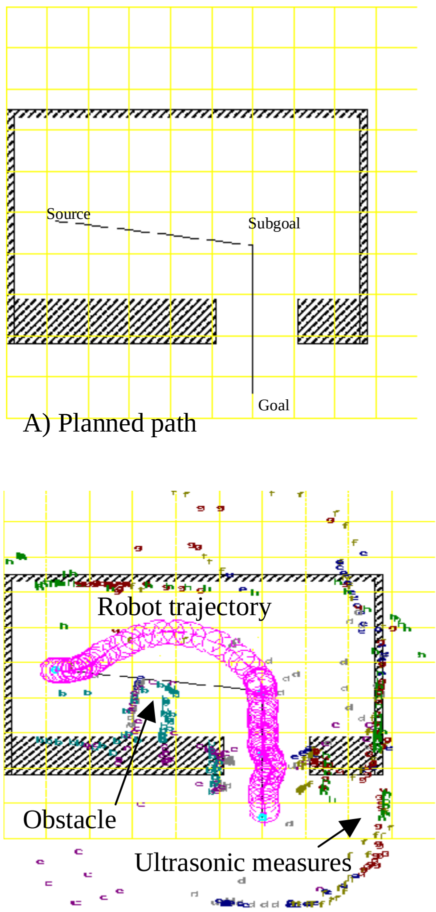


Figure 8: *Evolution of the partition of the universe of discourse for distance measures.*
L, R and F are respectively Left, Right and Front measure.
σ is the influence distance for obstacle avoidance.

The fusion of those behaviours - Goal-seeking and obstacle avoidance - 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, following a linear rule. Figure 9 Shows an example of navigation in automatic mode. All these results are detailed in [13].

The resulting comportment of the robot looks like human comportment. Human being follows the direction in which the object to reach is. If there is an obstacle on the way, he/she avoids it and then goes back to the initial direction. Using fuzzy logic, based on rules created by human experts, gives the robot human like behaviour for obstacle avoidance.

In automatic mode, this comportment is totally used. In shared modes, the operator can perform goal-seeking behaviour and the system realises obstacle avoidance. For example, the operator drives the camera and the robot follows the direction given by the camera. The operator can also manually pilot the robot by giving a direction, obstacle avoidance being performed by the machine.



B) Robot navigation with obstacle avoiding

Figure 9: *Fusion of two behaviour, obstacle avoiding and goal-seeking for robot navigation.*

6. 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. In this approach, the camera is not used. 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, algorithms must be robust to erroneous measures and stay under human control to manage difficult situations which can not be solved automatically.

6.1 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, 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 is localisation algorithm woks correctly. The main problem is that those three types of information are not completely reliable. To ensure a high localisation performance rate and to avoid the rejection of the assistance system by the disabled people we propose a man-machine co-operation, which can be divided into three levels. In the first level the robot automatically computes its situation during a move in the flat by fusing ultrasonic data with odometry: this is the on-line localisation. If the person detects a problem he runs the second level: this is the off-line localisation. 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.

6.2 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 measures 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 [14].

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 regularly. With a poor perception system, strategy must be different and must take into account the categories of odometrical errors ([15]). 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 a decision.

6.3 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 in unusable. 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 of 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 taken as a discriminating element. Exhaustive results are given in [16].

6.4 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. [17] 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 feedback information 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 incapacity 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 error

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. 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 1 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 1: *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 of 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. If the detection level is less than a predefined threshold, the robot detection can be considered as correct. If the detection level is higher than the predefined threshold, 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 that the detection is correct.

7. Conclusion and further work

Assistance robotics for disabled people can emerge 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 system complexity 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 point of view, the robot appears as a tool able to act on the environment. The person adds high level perception and decision means to the robot. 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 one of the shared mode the person pilots the pan and tilt camera inside the flat as though he was physically in the distant room: the robot becomes transparent. Giving the robot human-like behaviour facilitates mode changing. Indeed, the operator must understand the robot automatic behaviours to take the control of the robot. Task allocation is a very important aspect of the system. Assisted explicit dynamic allocation is currently studied to give the best decision assistance to the operator with the final decision taken by the operator.

Localisation is the 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.

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9. Figure caption

10. Table caption