ARPH - Assistant Robot for Handicapped People - A pluridisciplinary project

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ABSTRACT

Several projects are in progress in the field of disabled people assistance. Their main particularity is pluridisciplinarity. Technological solutions must be validated by psychologists and disabled people at each step of development to be accepted by end users. ARPH is a manipulator arm mounted on a mobile robot which aims at restoring the manipulative function of an handicapped person. The localisation of the mobile base in indoor partially known environment is an important point. Automatic movements of the mobile robot have already been studied. The analysis of different shared control modes is in progress. Human-machine co-operation is one of the main focus points of the project. Disabled people want to act on the system but do not want to see it working on its one. More, human intervention in the control permits to limit the complexity of the system. In order to make this co-operation effective, the main idea is to give the robot human-like behaviours.

Key words: Disabled people assistance, mobile robotics, localisation, human-machine co-operation.

INTRODUCTION

Disabled and elderly people face daily difficulties with respect to vocational, daily living and spare time activities. Robotics can provide technological solutions for completing medical assistance. The objective is to give persons some hours of independence without the presence of a third party. Manipulation is at the centre of some main life functions listed by WHO (World Health Organisation) [WHO99] such as carrying, picking up, moving objects. Rehabilitation robotics aims at partially restore user's manipulative function by interpose a robot arm between the user and the environment.

Robotic assistance system can be divided into three main configurations. HANDY1 [Topping98] or RAID MASTER [Kawamura94] are table-mounted manipulators which operate in a known environment. Another way consists of mounting a manipulator on a powered wheelchair. Several demonstrations in real situations, with the most known of them called MANUS, show the adaptability of the approach which adds to indoor outdoor operations. The last configuration is the most complex but the most versatile one and overall, it could be used by severely disable for example bed ridden or quadriplegic people. In this case a manipulator arm is mounted on a mobile base. However contrary to the first two configurations, notably HANDY1 and MANUS, this one is not marketed and stays at a research level. It is due principally to the difficulty for controlling a complex robot in a partially unknown environment and the cost of an autonomous robot. If it is assumed that the assistance system must not substitute but rather compensate for the activity deficiency of people with disabilities, a semiautonomous robot allows the repartition of subtasks between user's and machine skills. In fact the approach which seems attractive poses the co-operation problem which must be dynamically adaptable related to disability, system learning, person state in term of disability but also fatigability or wish. The adaptability is allowed by a variable task allocation which depends on autonomy abilities of the robot.

The ARPH Project, aided by AFM, French Association against Muscular dystrophy, consists in developing a semiautonomous arm mounted mobile robot. Section one presents the state of the project notably robot structure, perception system, control and information feedback architecture. The two following sections describe key works in progress, robot localisation and co-operation between human and machine (CHM).

Robot autonomy requires a correct localisation. In a partially known environment, that is to say modelled for a part, without transformation of the house literature does not propose reliable solutions. As in classical approaches our localisation method corrects dead reckoning regularly by information provided by a camera. In order to take into account the lack of camera data the algorithm adjusts parameters updating.

The person remote controls the robot through what is called control modes which can be considered as the emerged part of CHM. User builds a succession of control modes to carry out a task. Answers proposed in section three aim at simplifying shift in control mode in order to allow for the building of specific strategies that are better adapted to the person's handicap

PROJECT PROGRESS REPORT

ARPH (Figure 1) is a project begun in 1994. The main objective is the restoration of some deficiencies due to motor handicap. The first step of the project was to work on the mobile part of the robot called base. This study is divided into two stages: autonomy and man-machine co-operation. The second step deals with the manipulative function using a manipulator arm.

This section presents the state of the project about the mechanical structure, the control data-processing architectures. Then the end of the section proposes solutions to palliate person deficiencies by using ARPH.

Figure 1: *ARPH - Assistant Robot for Handicapped People*

Mechanical structure

Mobile robot

The mobile base is a sixty centimetre large and sixty centimetre high semi-circular robot. The dimensions are compatible with an indoor utilisation. DX system is used to command the motors of the robot. The choice is driven by the large diffusion of DX devices for powered wheelchairs. It is reliable and easy to maintain.

Different kinds of sensors are used. A dead reckoning sensor gives the position of the robot. As presented in the localisation section, it is easy to use but not relevant for long distances. Ultrasonic sensors permit to avoid obstacles (see navigation section). A video camera gives the operator feedback information about the displacement. It is also used for localisation.

Manipulator arm

The onboard manipulator arm is a MANUS arm. This device is more and more used in disabled people assistance systems ([Martens01]). It has been tested by many disabled people during long periods. Evaluation are encouraging for the future ([Evers01]). Up to now MANUS is used only mounted on a wheelchair.

Control architecture

Control architecture is based on a multiprocessor system. One PC is used for the person to command the system. It contains a Man-Machine Interface (MMI) developed on ARITI model ([Otmane00] and [Otmane00b]). A second one is onboard. They communicate by TCP/IP link.

The onboard PC pilots the different functionalities of the robot. A microcontroller card pilots ultrasonic sensors and dead reckoning. Ultrasonic sensors are activated by request. Dead reckoning position is automatically calculated on this card by interruption and sent to the PC by request. A serial link or a CAN bus links the card to a PC. DX system, which commands the movement of the mobile base, is based on CAN bus, but protocol is not public. A DX-KEY must be used to pilot motors. It is a sort of table of variables. Each of them is linked to a motor command. PC has just to read or write them It is connected to a PC via a serial or parallel link. The arm, MANUS, can be piloted via a CAN bus. Simple commands can be used or more complex ones have been developed in COMANUS European project ([Abdulrazak01]).

Data processing architecture

The two PC build up a client-server architecture. The client, only containing the MMI, gives user the possibility to interact with the robot. It presents two kinds of view. The first one is a video image possibly augmented with artificial elements as an augmented reality technique. The second one is an artificial view of the environment and robot: this is virtual reality technique in this case. Different end user interfaces are studied: keyboard, mouse, joystick.

The server is on the robot. In addition to the Ethernet link, it has to pilot the robot. Using the seven layers of ISO model, it is possible to distinguish three layers on the robot. Physical and data link layers are presented in the previous section. The application layer is based on mobile robotics classical approach. To pilot a robot, three functions are necessary (see palliated functions section): planning, navigation and localisation. The first two are combined to pilot the robot, using information of localisation. A perception task is also available. They are being implemented on a Linux system.

Palliated functions

World Health Organisation (WHO) has listed functions which can be impaired ([WHO99]). Several of them deal with object manipulation and displacement to look for something. ARPH proposes solutions to palliate those impairments. Three kinds of missions can be performed:

> 1- go and take back an object
> 2- go to see
> 3- explore

Mission 2 supposes the person knows the place he or she wants to have a look. Mission 3 supposes the person does not know where to go.

For all these missions, displacement of the mobile base is the first action to realise. It is performed in two steps, using three control modes: automatic, manual and shared modes (see human-machine co-operation section). Planning is the first step. It consists of finding the right way to go from one point to another. It is realised automatically using visibility graph and A* algorithm ([Benreguieg97]). It can also

be realised manually or in shared mode. The second step, called navigation, consists in following the trajectory found in planning step. It is based on fuzzy logic working with ultrasonic measurements ([Hoppenot96]). It can also be realised manually if the operator directly drives the robot or through a shared mode. Both of these steps need to have information about the localisation of the mobile base. Once the robot has reached the right place, the second action is the manipulation of the desired object.

Two main problems occur. Firstly, it is difficult to locate the robot correctly. Localisation section deals with this issue. Secondly, because of the presence of the human operator who wants to act and the complexity of the system, a man-machine co-operation must take place to obtain a realistic solution. This question is examined in the last section.

ROBOT LOCALISATION

The mobile base moves in a flat the plan is known. Big furniture can be modelled too, but small furniture (tables, chairs…) can not. So the robot evolves in a partially known environment. In this context, planning step needs to know the position of the mobile base and the goal to reach to find a trajectory. Navigation also needs to know the position of the mobile base to see if the movement is correct or not. What is classically done in mobile robotics is to compute absolute metric position in a reference frame. The proposed approach is described just below.

Mobile base absolute metric localisation

ARPH localisation is based on the combination of odometry system and camera localisation system. The first one uses simple and fast algorithms but its error increases during robot displacement because of it is relative localisation way. The second one gives a stable and bounded error but the computing is iterative with converging time depending of the quality of the initial estimates of the location. Our approach consists of a two level localisation. In the first level, let us call it on-line level, odometry is used and the camera replaces periodically the results to limit increasing error and reach a defined accuracy. Approximate locations of the robot are provided by odometry to initialise camera location algorithm. The second level corresponds to the case robot is completely lost without even an approximate knowledge of its position. In this case the robot is generally stopped and the time constraint becomes less important. This permits more image data acquisition in several camera orientations. This gives maximum probability of correct localisation even without a good initialisation.

In this section we will focus on the localisation using a single perspective view. The method is model based

and assumes that intrinsic parameters of the camera are already computed by calibrating ([Horaud93], [Puget90]) and that a wire frame 3D model of the flat is built.

The approach follows five stages: image acquisition from current robot location, edges detection and contours segmentation for 2D features extraction, matching between 2D-image and 3D-model features, camera co-ordinate computing and finally robot co-ordinate computing. That work is interested in the fourth step only.

Mathematical formulation of the problem

Several previous works treated the problem of camera locating in 3-D environment using a set of correspondences between the model and the image geometric features. A part of them uses straight-line correspondences ([Puget90], [Lowe85], [Dhome89], [Liu90]). This section presents a method based on this principle.

Let consider a straight 3D line L_i defined by its direction vector $\mathbf{v}_i$ and its position vector $\mathbf{p}_i$ in a co-ordinates system related to the work space frame. $\mathbf{v'}_i$ and $\mathbf{p'}_i$ are the expressions of $\mathbf{v}_i$ and $\mathbf{p}_i$ in the camera frame. l_i is the projection of L_i in the image. Let $\mathbf{n}_i$ be the unit vector normal to this plane in the camera co-ordinates system (Figure 2). Let $\mathbf{R}$ and $\mathbf{T}$ be respectively the rotation matrix and the translation vector between camera and workspace frames. $\mathbf{R}$ and $\mathbf{T}$ express in fact the robot location. It can be written:

$$\mathbf{v}_i' = \mathbf{R}\mathbf{v}_i$$
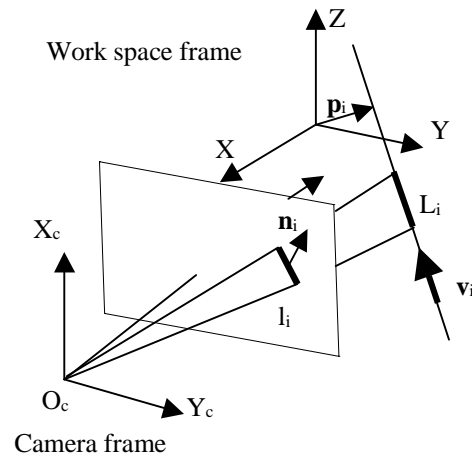$$\mathbf{p}_i' = \mathbf{R}\mathbf{p}_i + \mathbf{T}$$

Figure 2: *3D line perspective projection.*

As L_i and l_i belongs to the same projection plane, the two following scalar product equations are verified :

$$\mathbf{n}_i \cdot (\mathbf{R}\mathbf{v}_i) = 0$$
$$\mathbf{n}_i \cdot (\mathbf{R}\mathbf{p}_i + \mathbf{T}) = 0$$

A set of n 2D-3D straight-line matchings (i=1,2,3,…,n) leads to n equation couples. This equations permit to compute $\mathbf{R}$ by Levenberg-Marquardt algorithm and $\mathbf{T}$ by a linear least square method.

This method needs at least three line correspondences to compute the six location parameters (3 angles and three Cartesian co-ordinates). When the number of extracted features from the image is less than three, the strategy was to reduce the number of degrees of freedom of the system by assuming that the Z component of $\mathbf{T}$ is known and that the rotation around the Y axis of the camera frame is about zero according to the structure of ARPH ([Mallem96], [Talluri96]).

Results

The method was tested with synthetic and real images. Some results are presented in ([Aitaider01]). Globally, the error was about 2° for rotation and 10 cm for translation. This is considered accurate enough for ARPH application.

Alternative localisation solutions

Absolute metric localisation combines two characteristics. Absolute means with reference to an absolute frame. This is useful for global planning and global navigation. But for docking and manipulation tasks only relative localisation is required. In this context, relative means with reference to the object to take or the table to dock along. The second characteristic, metric, means precise localisation in the distance and orientation point of view. Unlike absolute characteristic, it is not useful for global planning and global navigation. But for docking and manipulation tasks precise localisation is necessary.

Interesting strategies are to be explored combining these two characteristics. The main idea is to associate metric information and topological or qualitative information ([Zimmer00], [Tieche99], [Thrun99]).

HUMAN-MACHINE CO-OPERATION

The implication of the person, the impossibility of a complete robot autonomy explain the need of a human machine co-operation. In the opinion of both medical staff and users, the robot must compensate only the disability without carrying out the whole task. In other side the presence of the person allows the conception of a less complex and less expensive robot in which some environmental perception or decision making are taken in charge by user.

The degree to which a person intervenes during the task is variable. It can begin by taking part in perception or decision functions until totally remote controlling the system. A user carries out a mission by choosing a control mode among a set put at his disposal. A control mode allocates degrees of freedom of the machine to degrees of control. For example during the displacement the direction of the mobile robot is driven by user and the speed by system related to the cluttering of the room. A control mode can be either automatic if the robot executes operation autonomously or manual if the robot is remotely controlled, or shared when the control of degrees of freedom is divided between human and machine as in the example above.

Co-operation can be seen at two hierarchical levels. At the strategic level user executes a succession of modes to perform successively a mission such as going and fetching an object. The problem at this point is to facilitate the mode change. In teleoperation the shift from an automatic to a manual mode is a well known difficulty for the operator. Shared modes illustrate the lower level of co-operation for instance user remote controls the main direction of displacement but locally robot can modify this order to avoid an obstacle.

Whatever the level a close co-operation depends on the understanding by the user of how the robot operates during an automatic operation. The suggested solution for improving comprehension is to give robot human-like behaviour. Our assumption is that, if the robot acts "as a human being", the operator would better understand its behaviour and then control it more easily.

Four main steps have been followed to apply this idea. First, human behaviour has been studied in natural situations by using psycho-physiological investigation tools and knowledge. Secondly, human strategies that seem more relevant have been extracted for modelling. Thirdly these models are implemented on the robot. As a last step, the advantages and disadvantages of this automation have been evaluated in psychophysical and behavioural experiments conducted in volunteer subjects. The final goal is to relieve the user of basic controls, which could be automated by way of sensorial and motor improvements.

This approach has been applied to the different functions needed for robot displacement planning and navigation [Otmane00]. What is presented in the following aims at describing by an example of the robot guidance the application of the method allowing the implementation of human-like behaviour. For more details see [Rybarczyk01].

Natural situation analysis

The visual information displayed to the operator, which is the major sensorial modality used in teleoperation [Terre90], helps him/her to anticipate the followed trajectory [Holzhausen91]. Human behavioural studies shows that anticipatory reflexes are present in human locomotion [Grasso96] and automobile driving [Land94]. Head orientation is

deviated with respect to walking direction, towards the inner concavity of the path [Grasso98].

Similarly, in a driving curve-negotiation situation, the drivers' gaze typically lies on the "tangent point" on the inside of each curve, seeking this point one to two seconds before each bend. The direction of this point relative to the car's heading predicts the curvature of the road ahead [Land95]. In summary, a "go where you look" strategy seems to underlie steering along curved trajectories.

Modelling of human strategy for implementation

By analogy between the human gaze and the onboard camera of the mobile robot, a control law of a camera similar to human gaze anticipation has been implemented. More precisely, the camera pan angle is conversely proportional to the curve radius of the robot's trajectory (Figure 3).
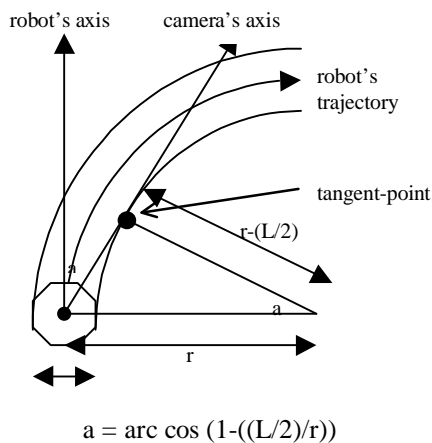

$$a = arc \cos (1-((L/2)/r))$$

Figure 3: *Geometry of the tangent-point of the inside curve.*

The camera rotation angle is computed by the curve radius (r) of the robot's trajectory, using trigonometric laws, here, $\cos a = (r-(L/2))/r$, where the semi-width of the robot equals $L/2$. The radius (r) is obtained by dividing the translation speed by the rotation speed of the robot

Experimental evaluation

The experiment evaluates the difference in operator remote-control by comparing the effect of a video feedback through a motionless camera or an automatic camera orientated to the tangent-point.

Procedure: the task of the operator is to remote drive the robot through a slalom route between 4 boundary marks. These marks are arranged in such a manner that the robot's curves are between 90° and 180°. The travel is carried out once in one direction and once in the other direction, in order to prevent the operator from developing too quickly a stereotyped travel strategy.

Fifteen subjects have been tested. The instructions given to the subjects were to carry out the travel, as rapidly as possible, while avoiding collisions with obstacles. For each session, performance was

evaluated by computing the execution time of the trajectory, the number of stops, and the number of collisions with boundary marks.

Results

The average time for the execution time of the travel is significantly lower with the mobile camera in comparison with the motionless camera ($F[2, 117] = 13.9$; $p<.0001$). The same significant effect in favour of the mobile camera has been obtained for the number of stops ($F[2, 117] = 29.8$; $p<.0001$), and the number of collisions ($F[2, 117] = 9$; $p<.0002$).

Discussion

Main result of this experiment concerns the mobility of the camera. Performance data are in general concordance with observations of human locomotion, showing that it is better to see the inside of the curve in order to control navigation. However, because the situation of the operator is *disembodied* compared with a more natural situation, it is difficult to define the best mobility gain of the gaze rotation. Indeed, gaze rotation angle in a direct situation is not necessarily the same as in a remote-control situation, especially because the camera's field of view differs from a human's field of view. However results have underlined that an adjustable camera depending on the robot trajectory acts as a compensation for the reduced camera field of view which leads to an improved driving control with softer trajectories, less stop points and less collisions, and finally a better confidence level of the operator.

CONCLUSIONS

The design of a semiautonomous robot for assistance to disabled people imposes a pluridisciplinary approach in which robotics proposes solutions for giving robot autonomy and psycho-physiological sciences elements for an efficient co-operation. In teleoperation, thanks to the possible intervention of user during the control process, the complexity, and so the cost of the machine, can be drastically reduced. However it poses the problem of human machine co-operation for a sharing of operation control. A key point is that automatic actions of the robot must be reliable and understandable for gaining the user's confidence. Current works are interested in both aspects: a reliable automatic localisation and a friendly guidance based on the observation of natural human behaviour. The assistance system is able to propose to a disabled user a set of control modes concerning the displacement of the robot in an indoor environment. The following step will apply the same approach based on human-like behaviour for building control modes of the manipulator arm.

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