

ARPH: An assistant robot for disabled people

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Abstract

Technologies or know how derived from robotic researches can contribute to the restoration of some functions lost by disabled people. However the over-cost generated by the additive potentialities must be affordable and related to the value of the usual product. In most cases, autonomous functions are direct transpositions of solutions applied in industrial robotics. If we consider that in addition with cost, security is a supplementary constraint of rehabilitation robotics, an important research effort is needed to propose technological components. The first part of the paper presents the system ARPH developed taking into account the constraints of the rehabilitation robotics.

Another aspect of assistance robotics is that the person is involved in the service made by the robot. Before and during the design process of an assistance device it is important to be sure that it will be "controlable".

Human aspects are studied following two directions. Is human adaptation ability sufficient for performing task through a complex machine and what human machine cooperation (HMC) could favor or improve the control of the machine?

1. Introduction

Robot applications or more generally technologies and know how derived from robotic researches have quickly evolved during the last decade to realistic products for medical applications. However the spreading of those products to general public is very limited for a great part due to the prohibitive cost and performances less than those hoped by users. More the diffusion of products is unequal if the application field is considered. For example, the rehabilitation market proposes manipulator arms such as Manus [1] or AF Master [2] but no smart wheelchairs. If we consider the contribution of robotics only concerns autonomous functions integrated to assistance devices. The over-cost must be related to the price of the usual product. It is one of the major brake on smart wheelchair spread.

Up to now the autonomy of assistance devices has been a direct transposition of solutions applied in industrial robotics. An important research effort is needed to propose technological components which are a correct compromise between cost, reliability and security.

Another major constraint of assistance robotics are human factors. An adequate cooperation between human and machine contributes to the improvement of the use of such sophisticated assistance. This point of view is not completely accepted by robotic community. However an appropriate cooperation gives several advantages and firstly a reduction of the robot complexity by using human skills for perception and decision making. The second interest is that disabled person feels involved in the service given by machine and no more completely dependant. It is an important aspect underlined by medical profession. Another human factor to be taken into account is the variability inside a same type of handicap. The system must allow the adaptation to the particularity of the handicap but also to other conditions for example, the fatigability or the learning level of the user.

However the more complex a machine is the more difficult the system control, especially in case of handicapped people. Before and during the design process of an assistive device it is important to be sure that it will be "controlable".

Does human adaptation ability is sufficient to allow a machine appropriation by user, in psychological sense of the world, even if the conditions of task execution are quite different from natural conditions?

And if the response is positive, what kind of human machine cooperation (HMC) could facilitate or improve the control of the machine?

In the framework of human-machine cooperation, the control is shared between the human operator and the machine. Through human behavioural studies, this sharing has been realized by leaving the higher levels of decision-making to the operator and the lower levels of control to the machine. More precisely, the control functions that are automated on the robot correspond more or less to human reflex-like behaviours. In the situation of teleoperation, the operator must pre-plan the trajectory of the robot, in order to achieve easier control of robot navigation. To do this, the visual information brought to the operator, which is the major sensorial modality used in teleoperation, must help him/her to anticipate the followed trajectory.

Different robotic approaches for people assistance have been presented in [3]. HANDY1 [4] is a table-mounted manipulators, which work in a known environment.

Wheelchair-mounted manipulators, such as MANUS [1], allow operations in indoor and outdoor environments. Mobile robot mounted manipulators, such as MOVAID [5] is the most complex but the most versatile configurations.

The paper presents ARPH –Assistance Robot for People with physical Handicap- which aims at assisting a person in manipulating and moving an object. The environment is supposed partially known, the floor plan and heavy furniture are modeled. The assistance device is composed of a manipulator arm mounted on a mobile robot.

The first session describes the whole architecture of ARPH justifying solutions related to application constraints. The second session presents one aspect of human machine cooperation. User builds its own strategies for controlling the robot by combining control modes which can be manual, automatic or shared. Share modes implies a cooperation between human and machine. It seems efficient to give robot human-like behavior during its autonomous action. In the last session, the question of the system “controlability” by a human user is evaluated by a study of his or her appropriation ability of the machine. A first set of experiments compares natural human performances with remote control performances during a task needed for object grasping.

2. Assistance device architecture

The system is composed of a control station and a manipulator arm mounted on a mobile robot (fig.1).

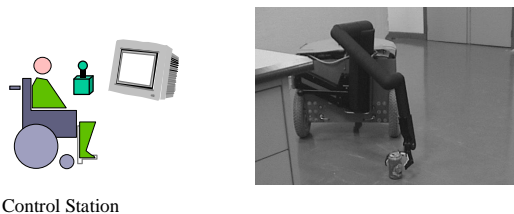


Figure 1: ARPH system

2.1 Robot structure

In order to respect a correct compromise between cost and reliability, hardware components are unless impossibility, commercial products (fig.2):

- perception : pan tilt camera Sony
- motorization : DX for wheelchair
- Manipulation : MANUS arm

We have developed :

- perception : dead reckoning and ultrasonic ring.
- mobile robot body : fiber glass. After cost evaluation the solution is cheaper than a modification of existing powered wheelchairs.

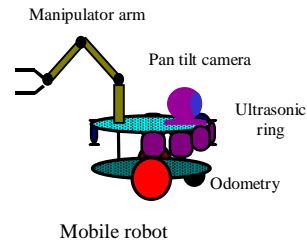


Figure 2: Robot architecture.

At the perception point of view, dead reckoning localizes robot in the environment, ultrasonic ring detects obstacle for avoidance. Camera plays three roles: i) a perception device which provides video feedback during the robot displacement, ii) a perception device for robot localization iii) a control device which provides robot the direction to follow or the object to reach or follow (auto-tracking mode of the camera).

2.2 Control station

The user remote controls the robot through the medium of a control station composed of : i) control devices adapted to the handicap of the disabled person, ii) a screen which displays different types of information via enhanced reality techniques, 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, virtual camera points of view, robot operating indicators (fig.3).

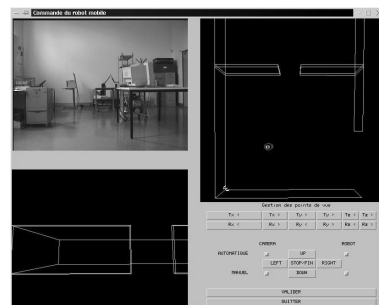


Figure 3 : Visual feedback of man machine interface

2.3 Distributed architecture

The architecture is adapted to the control of the robot through internet or intranet network which allows the teleoperation of robotic devices located in local or distant sites and so opens the system to other field of applications such as remote intervention in a hostile environment. In the case of ARPH, the control station is considered as a client and the robot a server which provides a set of services. In order to facilitate future evolutions, the architecture is divided into three sub-structures of client-server type, one for video feedback,

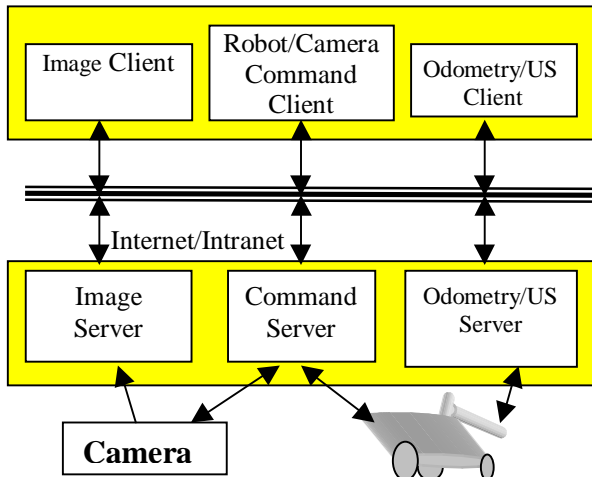


Figure 4: Distributed Architecture.

one for robot commands and camera pan-tilt commands, and the last one for dead reckoning and ultrasonic feedbacks (fig.4).

Each sub-structure is composed of three hierarchical levels of service.

User level is dedicated to high level tasks e.g. for object displacement and manipulation or remote vision for exploration.

Medium level puts together main functions such as perception, robot control and human machine interface Basic level is the set of functions which manage the different inputs and outputs:

- proprioceptive perception : dead reckoning of mobile robot, joint variables of manipulator arm,
- exteroceptive perception : ultrasonic ring, image acquiring,
- device control : US ring, camera parameters (zoom, ...) and pan-tilt orientation
- HF emitting or receiving for internet communication

3. Human machine cooperation: Control Modes

3.1 Control mode definition

The person builds strategies to succeed a mission. A strategy can be seen as a succession of control modes that user enables following evolution of needs for performing the task. Modes can be split into automatic, manual or "shared" type. The fact the modes are complementary gives users total freedom to elaborate their own strategy. In a "shared" mode, the degrees of freedom of the machine are controlled both by the man and the system. Many combinations can be imagined however it is important for avoiding command errors that the user understands how the robot operates during the execution of a shared mode. A well adapted understanding facilitates an efficient cooperation. An

other advantage is to encourage user to modify its way of control incitating him or her to often change mode and so elaborate more other strategies for the execution of more complex tasks.

The main functions needed for the displacement of the robot -planning, navigation and localization- integrates human like behaviors. Planning aims at defining the best path from a source to a destination and navigation ensures that the robot follows correctly the path avoiding obstacle. Obstacles are objects which are not known in the environment model. Table 1 presents different possibilities of ARPH control by using automatic, manual and shared modes for planning and navigation.

Table 1: Example of control modes for piloting the displacement of the robot

Function	Automatic mode	Shared mode (one example)	Manual mode
Goal designation	Object auto-searching	User controls the camera orientation, robot follows the direction indicated by camera with or without obstacle avoiding	User remote controls the robot using video feedback
Planning	Path planning		
Navigation	Follow up the path with obstacle avoiding		

Each mode is built from a set of basic functions. At present time, available autonomous functions are path planning, path following up, obstacle avoiding, mobile or not object tracking.

Most of shared modes implemented in ARPH system integrate functions using camera. This device is well adapted to give robot human-like behavior during its movement. Indeed, besides object tracking, the camera allows two ways of robot driving. Either, user controls the camera orientation and the robot follows the direction indicated by the camera as seen in Table 1, or the user controls the robot and, in this case, the camera is oriented with an anticipative behavior related to the curvature radius of the path followed by the robot. This point is discussed in next paragraph.

3.2 Robot human-like behaviours

We have proposed to give robot human-like behavior when it performs an autonomous operation such as obstacles avoiding or target reaching. It seems an efficient way to bring together robot and user by a common way of acting. After presenting the approach for planning and navigation we develop in details the anticipative behavior of the camera.

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 behaviour, the robot computes a path through the flat to reach the goal using the known flat plan. 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 goal, for example 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 behavior making the fusion of goal-seeking and obstacle avoidance. For goal-seeking, direction is defined by relative position of the robot and the goal. If a non modeled obstacle is on the robot path, it is detected by ultrasonic ring and the robot locally modifies its trajectory to avoid it.

Anticipative behavior of the camera. As for other human like behaviors seen before, four main steps have been followed to apply this idea. First, human behavior has been studied in natural situations, by using psychophysiological investigation tools and knowledge. Secondly, human strategies that seem more relevant have been extracted for modeling. In three, these models are implemented on the robot. As a last step, the advantages and disadvantages of this automation have been evaluated in psychophysical and behavioral experiments, conducted in volunteer subjects. The final goal was to relieve the operator of basic controls, which could be automated by way of sensorial and motor control improvements, following human-like behavior. The following gives the main aspects of the study which has been presented in [6].

Behavioural studies in humans show that anticipatory reflexes are present in human locomotion [7] and automobile driving [8]. Indeed, shifts in human head direction systematically anticipate changes in the direction of locomotion. Head orientation is deviated, with respect to walking direction, towards the inner concavity of the performed trajectory [9].

By analogy between the human gaze and the robotic camera, a pan pattern 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. So, the camera moves towards the tangent point of the imaginary inside curve created by the robot's lateral extremity (fig.5).

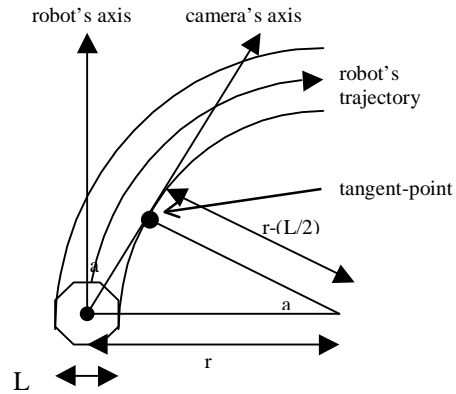


Figure 5 : Geometry of the tangent-point

The camera's rotation angle is computed by :

$$a = \arccos (1 - ((L/2)/r)) \quad (1)$$

Where L is the width of the robot equals L/2. and r the curve radius computed by dividing the translation speed by the rotation speed of the robot.

Experiment evaluates the quality difference in operator remote-control, by comparing the effect of providing sight through a motionless camera or through an automatic camera moved to the tangent-point.

Experimental procedure. The operator has to manoeuvre 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°.

Results. Experimental results have underlined two main features : a moving camera depending on the robot trajectory and a small tilt angle allowing the operator to see the front of the vehicle. These features, acting as a compensation for the reduced camera field of view, have lead to improved driving control with softer trajectories, less stop points and less collisions, and finally a better confidence level for the operator. Performance data are in general concordance with observations of locomotion humans, showing that it is better to see the inside of the curve in order to control navigation.

4. Human machine cooperation: Robot "controlability"

4.1 Appropriation principle

By definition, carrying out a teleoperation means "indirectly acting on the world", through a remote-controlled machine. In the case of our rehabilitation robot destined for daily use by disabled people, we can question ourselves about the human capacity for appropriating a robotic-arm which isn't one's own. Indeed, if we have good knowledge on the technical efforts made to improve the human-machine cooperation at the interface level, as well as the control and function modes of robots [10], little has actually

been researched on human efforts made to adapting oneself to machine.

In order to make a first attempt at answering questions on the human capacity to appropriate a machine, we have carried out an experiment whereby a comparison was made between direct and indirect (the use of a Manus robotic arm) human performance in a task of estimating the grasping distance of an object. To be more precise, we have researched the human threshold of precision in estimating the borderline between the peri-spatial field (space surrounding the robot) and the extra-spatial field (space outside of the grasping distance) of the robot, by comparing a person's precision of estimation of the borderline between his peri-personal space (space surrounding the body) and the extra-personal space (space outside of a grasping distance).

The relevance of this task is that it involves fundamental neuropsychological concepts of the notion of embodiment. Indeed, studies have showed that this dichotomy between the peri and extra-corporal space is not only descriptive, but has physiological bases too [11]. Besides, this body schema appears to be relatively dynamic because its outline would be distorted by the use of tools [13]. Thus, by utilizing direct human performance as reference value, we were able to evaluate if the peri-corporal space of the teleoperator extends, in the same manner, to that of the robotic arm, which would thus be proof of appropriation.

4.2 Experimental procedure.

The experimental device was composed of a table with four graduated axes. These axes radiated from one of the edges of the table between 40 and -20 degrees, with an interval of 20 degrees between each of them. The convergence point of each axis was centered on the human cephalic axis for direct experimental condition, and on the visual axis of the camera, for indirect experimental condition. Hence, the zero-degree axis was located in front of the visual axis of the human being, like that of the teleoperator. The 40 and 20-degree axes were located on the left of their visual field while the 20 degree axis, on their right. Testing first began with the left arm of the subjects and with a configuration of the robotised system categorised as "left", which was a situation in which the manipulator robot was located on the left side of the camera. As a control, the experimental device was reversed to test the right arm following this.

The experimental procedure was divided into two stages. The first one was the training stage where the teleoperator, like all humans, evaluated the range capacity of the robotic arm as well as that of his own arm respectively. This was carried out by grasping a cylindrical object placed at different distances on each of the four axes. This stage also served as calibration, in order to find out the real capacities of extension for each of the two arms, and to compare them with estimations given in the next stage. The second stage consisted of

finding the threshold distance, according to the condition, for which the subject estimated if the object presented exceeded the grasping distance of his own arm or that of the robotic arm. For this, the experimenter randomly changed the position of the cylinder along each axis and asked the subject to reply "yes" or "no" to the following question : "Are you able to grasp the object presented by a simple extension of your arm ?".

4.3 Results.

After the data collection, the "P" ratio of the estimated threshold distances divided by real threshold distances was computed for the different axes and for all experimental conditions. Therefore, Figure 6.a represents this "P" ratio distribution according to the four axes, for the human condition and for the "left-arm" configuration of the robot. The first observation was that, although the two curves are not superimposed, there was a statistically significant augmentation of the "P" ratio from 40 to -20 degrees of the experimental space for both conditions ($F(3,18)=4,11; p<,0220$).

To gauge the level of similarity between the left-arm direct human performance and the performance carried out through the "left-arm" configuration of the robot, the correlation coefficient (r) between the two curves (this coefficient expresses the strength of relationship between two variables from 1, for a perfect positive relationship, and -1, for a perfect negative relationship) was computed. The result of this is $r=1$. This perfect positive relationship is justified by Figure 6.b, which represents the "P" ratio of the robot (P_r) to that of the human (P_h) according to the four axes. The director coefficient which was almost equal to zero of the regression line ($y=0.0029x+0.9211$) of the distribution of these P_r/P_h ratios on all of the axes confirms the similarity between direct human performance and indirect human performance.

In order to control the validity of this result, an experiment identical to the last one was carried out by asking at the subject to do a perceptive estimation, this time, with reference to extension capacities of his right arm. If our assumption of identification between the operator's arm and robot arm is right when the two arms are in the same configuration, a parallel performance must not be achieved (like in the next experiment) but, on the contrary, a crossed performance must be achieved by comparing the ratio of the "left-arm" configuration (P_r) to that of the right-arm (P_h). And indeed, there is a statistically significant difference ($F(3,24)=3,68; p<,0259$) for the interaction test between P_h right and P_r left according to the experimental axes.

4.4 Discussion.

The most important result of this study is that the spatial anisotropy of the visio-motor human system seems to be conserved when the human being acts indirectly on the environment, through a manipulator robot. This

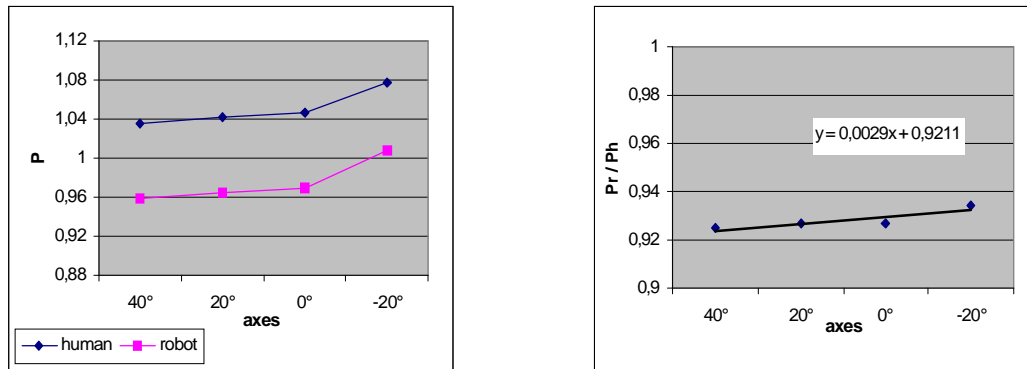


Figure 6 : a) Ratios P in the left arm situations

b) Ratios P robot on P human

observation is a strong experimental argument to say that the teleoperator identifies the robot arm as an extension of his own arm. Therefore, this phenomenon agrees with our appropriation assumption of the machine by the human being. If our subsequent research confirms this phenomenon, it will generate important consequences about the visio-motor architecture of a robotics teleoperated system by advocating the importance of making an anthropomorphic configuration to improve the human-machine co-operation.

5. Conclusion

ARPH is a system in constant evolution. At each step it is evaluated by experiments in which several subject are involved. Robotic component which gives it some autonomy are chosen or designed specifically for respecting the particular constraints of rehabilitation domain.

The participation of the user to the task the robot is performing is one of the main characteristics of technical assistance. We study human aspect following two research directions. The first one concerns the person ability for adapting himself to the control machine though action means are far from natural conditions. The second point belongs to human machine cooperation. Our point of view is that a person executes a task in an incremental way. The approach we propose allows user the building of its own strategies from a set of control modes which are complementary and partially redundant. Each disabled person exploits the subset of control modes adapted to his or her own handicap. If the user needs evolve during the time for instance because of learning effect, he or she re-imagines a novel strategy.

6. References

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