Remote control of a biomimetics robot assistance system for disabled persons

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Abstract

The goal of the ARPH project is to restore autonomy to disabled people by increasing their field of intervention. The process will involve an assistive system composed of a mobile robot-mounted arm and a control station that allows it to be remote-controlled. The human-machine cooperation will take place through a client-server computational architecture. The ergonomic question therefore is to find out the cognitive problems involved when an operator carries out a remote control action on the environment. Thereafter, we shall proceed to examine how behavioural neuroscience can bridge the existing gap between humans and machines. This gap is categorised as “disembodiment”.

In the course of our research, the reduction of the disembodiment was studied in two ways. Firstly, from the robot to the human, by evaluating how the implementation of human-like behaviour of the visual anticipation on the steering can improve the robot control. Secondly, the study focused on the human-robot sense, by testing if we can observe appropriation signs of the machine in the body schema of the operator. All the results are discussed in terms of pertinence of the neuroscientific approach for the conception of physical and functional architecture of a teleoperated robot of rehabilitation.

Keywords : rehabilitation robotics, remote-control, biomimetic, behavioural neuroscience.

I – Introduction.

Robotics applications dedicated to medicine, based on technologies and know-how derived from researches, have evolved quickly during the last years from scientific researches to reality, especially in two domains: surgery and assistance to disabled and/or aged people, at home as well as in hospitals or specialised institutions.

In the assistance domain, robotics contribution concerns autonomous functions integrated into mobile systems like wheelchairs and gripping. Objects manipulation requires the use of a manipulator arm. Many configurations have been tested : fixed arm, arm embarked on a wheelchair or on a separate mobile base. The last configuration has been chosen in LSC for ARPH (French acronym for robotic assistance to disabled people) project because of its possibilities to be used by persons with heavy impairment and the possible extension of the application field. Indeed, a manipulator arm can be used in direct vision control or remote control. The second case is called teleoperation.

Desk Robotics assistance is already on the market as MANUS [1] or AFMASTER [2]. But their distribution remains extremely restricted, largely because of a prohibitive cost and of performances considered lower than those waited by the user.

What one can call an additional cost can be explained by the fact that robotics solutions used in the systems of assistance arise directly from the industrial environment from which the economic and technical constraints differ strikingly. It seems necessary to carry out an effort of supplementary applied research to conceive autonomous functions respecting the constraints notably of costs of this domain in particular for the perception functions. The transposition of solution of the industrial world was also translated by a will to make the robot the most autonomous as possible. In fact, in the field of the assistance, the person should be actively involved of the service given by the machine and it is necessary to interest in a co-operation among the person and the semiautonomous machine with as consequence a reduction of the complexity of the machine and so the cost. As regards the ARPH system, we attempted to develop these various aspects : the autonomy with automatic functions adapted to the specific criteria of the domain of the assistance and the man-machine co-operation.

The paper articulates in two parts, a general presentation of the current state of the system ARPH by insisting on the problem of localisation, followed by a more complete development of our approach of the Man-Machine Cooperation (MMC). The state of the works in co-operation depends on the concerned function. As regards the mobility, the operator has to his/her disposal a set of command modes, automatic, shared and manual ones which are complementary and redundant. The works on the manipulation of objects are situated at a more theoretical level because we are interested in the notion of appropriation of the machine by the operator in a context of gripping of objects. It is to note that the man-machine interface which can be considered as the emerged part of the MMC is not described but is based on virtual reality and augmented reality.

II – System description.

WHO (World Health Organisation) defines exactly a set of features being able to be altered by a handicap. In particular, "to go and to take an object", "to go to see" and "to investigate" are associated to physical handicap.

The ARPH system tries to palliate these incapacities. It consists of a mobile base carrying a manipulator arm called Manus. It is endowed with DX engines to use a standard spread in the electric wheelchairs to take advantage of their reliability and the capacity of maintenance of the current retailers. Various sensors assure a capacity of autonomy of the robot: odometer, ultrasonic sensors and camera.

ARPH's command is based on computer architecture of client-server type (Figure 1). The server PC is embarked on the mobile base. It pilots engines via the interface proposed by DX : the DXKEY. Ultrasonic sensors and the odometer are piloted through a microcontroller card, which eases the PC of the treatment. The pan-tilt camera is piloted through a serial link.

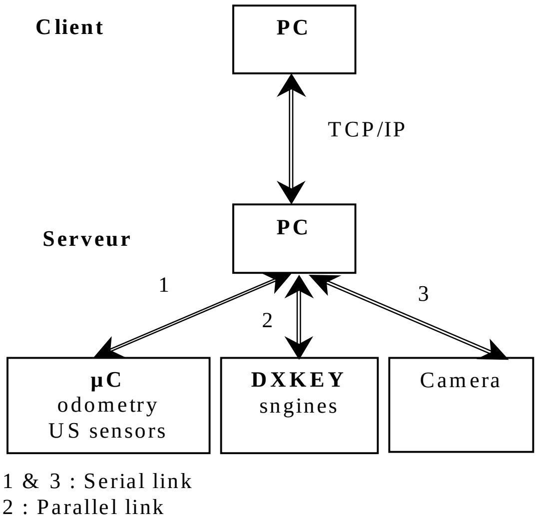

Figure 1 : Client-server architecture.

Clients can connect to this server by Internet by means of a classical navigator. This structure, inspired by the system ARITI developed in the CEMIF-LSC [3], allows to several clients to ask for the access to the machine. In the case of a use in institution this possibility allows to share the system among several persons.

III – Autonomy of the assistance system.

The objective of ARPH is to give back a part of autonomy to handicapped persons. The robot must not act in place of the person but assist him/her in tasks which he/she can not carry out alone. The realisation of a mission is based on capacities of perception, decision and action. Both man and machine have these capacities. The autonomy in robotics is at first studied, and Man-Machine Co-operation is then presented.

The command of an autonomous mobile robot leans on three pillars. Planning consists in generating a trajectory connecting the current position of the robot with the goal wished from the knowledge on the environment and the robot. A classical technique uses obstacles dilatation to take into account the dimensions of the robot, generation of a visibility graph enumerating all the possible paths between two summits of obstacles and finally search for the shortest path by using a minimisation algorithm, for example A* [4]. The phase of navigation takes care to follow the trajectory defined during planning. If the modelled environment is identical to the real environment and if the position of the robot is known exactly during the movement, it is simple. If unknown obstacles are on the trajectory, it is necessary to avoid them thanks to exteroceptive sensors. ARPH uses ultrasonic sensors. The avoiding strategy is based on fuzzy logic [5].

These two phases can take place suitably only if the position of the robot is known with enough precision. There are two big families of localisation: the relative one is based on proprioceptive measures of movement (odometry for ARPH), the absolute one uses exteroceptive measures (camera for ARPH) and deduce the position of the robot by comparing them with the known parts of the environment. The first technique is simple and fast. The major drawbacks are the drift during time and its sensibility to wheels slippage. The second is more complex and less fast but it supplies results the error of which is not a function of time. It is then classical to combine both methods: the relative localisation is corrected regularly by the absolute one. This last one being more expensive in times of calculation, indicators are calculated before its computation. From the only information resulting from sensors (here an image), they give an a priori knowledge onto the maximum precision of the results. If it is not sufficient, only the odometry is taken into account, waiting for the next absolute localisation computing.

If the robot is totally lost, only absolute localisation is operational. It will be sometimes necessary to stop the robot and to take images to find the position of the robot. The process is then no more real-time.

The absolute localisation splits into five stages: image acquisition, extraction of 2D-primitive from segmentation, matching of the 2D-image with the 3D-model, computation of the co-ordinates of the camera in the absolute frame and finally calculation of the co-ordinates of the robot in the absolute frame. Phases number three and number four are presently the most critical. Phase number two asks for a compromise between the quality of the extraction of primitive and the real time. For ARPH, two methods of calculation of the co-ordinates of the camera (phase number four) are compared, one based on Horaud's principle [6], the other one on Lowe's one [7]. Each of these methods suggests and calculates six degrees of freedom (a rotation and a translation). The originality of this work is to present adaptations of these methods to the mobile robotics: knowledge of height, pitching and rolling permits to limit the system to three degrees of freedom. First results of simulation show that both methods allow to localise the robot with a sufficient precision (1 to 2 degrees and 10 to 20 centimetres of error for a level of realistic noise) for an application of movement in structured environment in most of the situations with at least three visible segments.

IV – Cognitive problems.

To allow a disabled person to handle a remote control robot gives him the possibility to enlarge his field of intervention on the environment. However, this situation will involve lots of cognitive problems. They are caused by the fact that the human being can only produce an indirect action on the environment and, in the same way, can only indirectly receives the results of this actions [8]. That means, lots of sensory-motor sensors and their interconnections do not work like in the situation of a direct natural action.

So, even if it is now possible, with the advancement of technology, to retransmit the majority of sensorial modalities (sight, hearing, touch) to the teleoperator, there is still an important gap between the natural dexterity of the human being and that carried out through a teleoperated robot. This gap is, partially, caused by the fact that our capacity of perception of the world can not be summarised by the five senses. We tend to neglect the importance of essential sensorial sensors like vestibulare sensors, that inform us about the body orientation in space, and especially proprioceptive sensors that give information on movement and relationships between the different body elements [9].

It is important to note this late modality, because it defines well the scope of the main problem that a human being encounters carrying out an action by teleoperation. This problem could be summarised by the term “disembodiment”. Indeed, proprioceptive sensors are really the main components that give the human being the sensation of belonging. They are the ones which inform the brain about the body position, of its different segments in space, and of their movement dynamics on-line.

According to neuroscientific studies, it is because the human being belongs to a body and acts through this particular body that he can adapt to the world, by constructing his own body schema [10]. But, in the situation of an action carried out in teleoperated conditions this adaptation seems limited, because there are two physically distinct entities.

Nevertheless, it is known that the brain has a very important plasticity that gives the human being a big learning capacity to adapt to lots of new situations. So, it is the study of human capacities to adapt to act through a body that is not his own, that will motivate our future studies. In others words, the question would be to know more exactly the disembodiment level between the operator and the robot, its modulation with the learning time and discover if, in the end, the human body schema extends to the machine.

To do that, a double exploratory strategy has been used (Figure 2). The first, was made in a “robot-human” sense and was used to test the improvement of the human-machine co-operation after the implementation of human-like behaviour in working of the robot. The second, was made in a “human-robot” sense. It was used to study the eventual appropriation in the human body schema in the course of time.

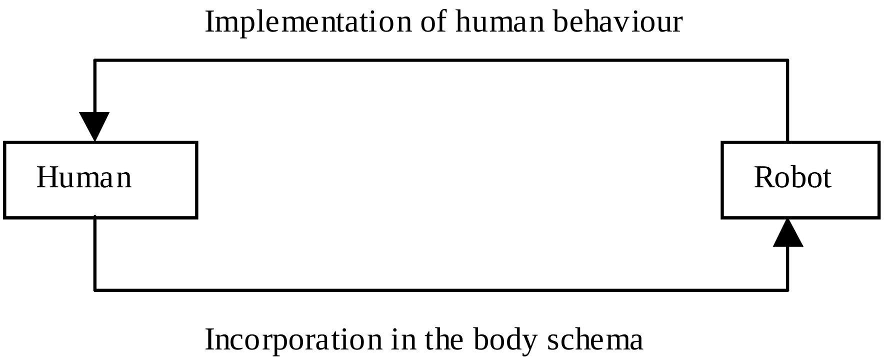

Figure 2 : Model of the principle of “disembodiment” reduction.

V – Implementation of human-like behaviour.

a. The example of the visual anticipation behaviour on the steering.

In the course of evolution, the brain developed in such as manner as to allow the anticipation of future actions. Moving to escape from a predator or hunting a prey, involves making hypotheses on the world to predict the intentions of others. Thus, it is not a simple reflex, as a passive response to a sensorial stimulus, but on the contrary, the action control necessitates the brain to be a predictor which simulate actions of the others as well as those of oneself.

For example, during the catching movement of a ball, the neurophysiological recordings show that the brain never waits for the sensors to be activated to begin to respond. In this situation, the brain produces a contraction of the muscles, 300 ms before the object touches the hand [11]. In the same way, there are neuromuscular spindles in the muscles which can measure the stretching and which have a sensibility modulated by the brain. This means that the brain can influence the perception at its source and, therefore, the action influences the perception.

Thus, as regards locomotion, the brain acts on the rest of the body in order to organise the movement not from the feet to the head, but from the head to the feet. The head is used by animals like an inertial centre of guidance, stabilised in space from which body movements are co-ordinated. This is due to the fact that this is the part of the body that supports the eyes. Indeed, the gaze is one of the most fundamental components of our steering control in space. It is chiefly by this means a person interacts with the environment, to guide his walking, to avoid obstacles.

Therefore, in order to carry out a fast and regular movement, the human being uses the predictive properties of his brain. Hence, neuroscientific studies have showed that when a subject must turn around an obstacle during locomotion, his cephalic axis does not stay aligned with the rest of the body. It appears that for curved trajectories, the head orientation is deviated with respect to walking direction, towards the inner concavity of the performed trajectory. Precisely, the head direction guides the steering by systematically anticipating changes in the direction of locomotion with an interval around 200ms[12].

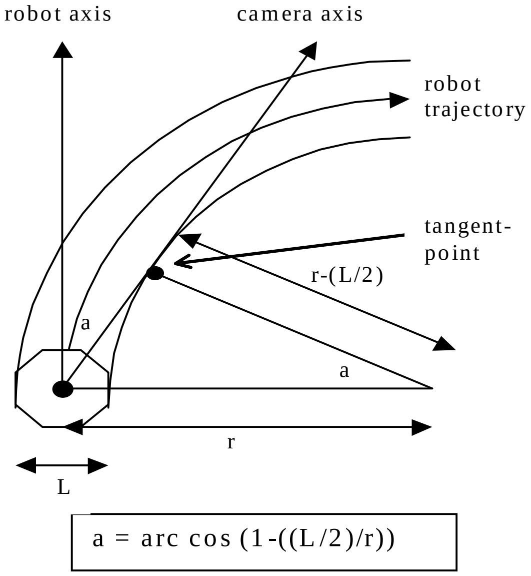

Figure 3 : The camera rotation angle is computed by the curve radius (r) of the robot trajectory, using the trigonometric laws. Here, cos a = (r-(L/2))/r, where the semi-width of the robot equals L/2. The radius (r) is obtained by dividing the translation velocity by the rotation velocity of the robot.

Modelling. It is this type of fundamental behaviour, of visual anticipation on the walking travel, which has been implemented on the mobile robot. To do that, an analogy has been done between the human gaze and the pan camera mounted on the robot. Therefore, an anticipatory behaviour of the pan camera has been automated according to the steering remote-control carried out by the teleoperator, following the model of the Figure 3. It shows that the camera pan angle must be conversely proportional to the radius curve of the robot trajectory, in order to move the camera towards the tangent point of the imaginary inside curve created by the robot lateral extremity.

Experimental procedure. The operators were placed in an indirect visual condition. They had to manoeuvre the robot through a slalom route between four boundary marks. These marks were arranged in such a manner that the robot curves were between 90° and 180°. The travel was carried out once in one direction and once in the other direction, in order to prevent the operator from developing a stereotyped travel strategy too quickly. Ten subjects have been tested : two independent groups of five subjects have passed the two main conditions (with or without anticipatory movement of the camera). Groups were independent to avoid a confounded learning effect. After a short trying session, each subject has realised eight testing. 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. Experimental results show an important advantage of the anticipatory camera condition in comparison with the teleoperator performance in motionless camera condition (Figure 4). Like this, the average time for the execution of the travel is significantly lower with the mobile camera in comparison with the motionless camera (*t* de Student = 2.44 ; p = .03). In the same way, the regularity of robot trajectory is significantly better when the robot is controlled through a camera which anticipates on the steering for : the average number of stops (*t* de Student = 2.02 ; p = .03) and the average number of collisions (*t* de Student = 2.41 ; p = .03).

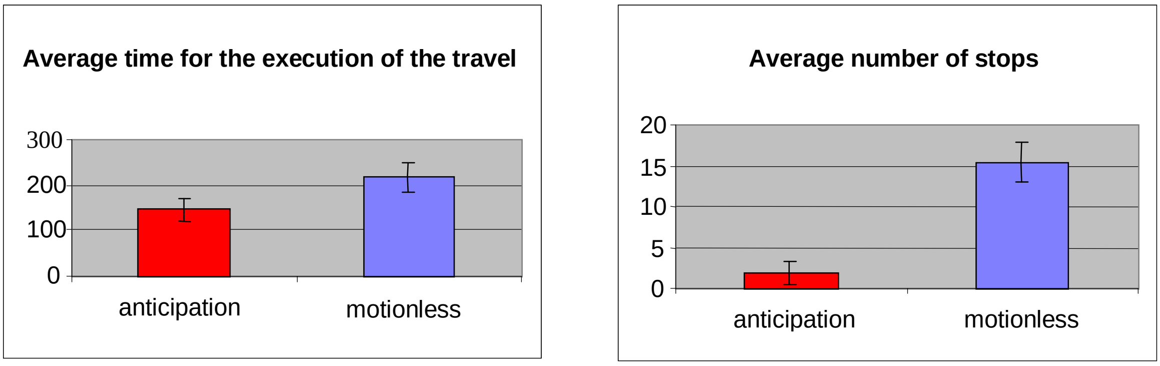

Figure 4 : Experimental results.

Discussion. This data show that it is better to get a visual information on the inside curve of the trajectory, when we have to remote-control a robot though camera vision. In this situation, the operator seems more rapid to execute a travel, has a more secure steering control and a better confidence level in his trajectories. These results agree with the observations done on the human gaze orientation during the locomotion or driving control. In conclusion, the experimental approach which consists of modelling human behaviours, improves the human-machine cooperation by mitigating the “disembodiment” of the teleoperator in relation to the teleoperated robot.

b. Generalisation of human like behaviour.

The user pilots the machine through a set of control modes. The role of a mode is the affectation of a command to a degree of freedom of the robot. The source of commands can be the user, the system or both the user and the system. Following that distinction, it exists three types of control modes : manual, automatic or shared modes. The user disposes of a complementary but also partially redundant set of modes which allows the building of strategies adapted to the level of handicap, the user's needs and preferences and the complexity of the task to be performed. As we have seen before, when the robot executes automatic operations its reaction is similar to human behaviour. Such robot response aims at facilitating the cooperation between both entities by facilitating the understanding of the manner the robot operates.

Presently, different control modes have been implemented on the robot, each one of them has a more or less high automation level. This has been made voluntary, in the goal to provide the operator an optimal flexibility in his co-operation with the machine. In fact, if the automation has the capacity to reduce the operator’s mental workload, it has negative effects as well. For example, it reduces the attention level or increases his difficulty to regain control after the automatic step of the robot [13].

Therefore, projecting a human being outside the control loop of the machine is the first thing to avoid, if we want to make an efficient automation of a semiautonomous system. In contrary, the operator must ever stay the central part of the human-machine system. He must be actively involved in the task and adequately informed about the general state of the automation [14]. The different automation levels of our robot control modes were made in this manner, which we briefly present in the next paragraphs. The process which develops the manner the modes has been obtained is more precisely detailed in Hoppenot and Colle, 2000 [15].

At first, there are *manual navigation modes* in which the operator controls the robot wheels to guide the displacement. To do that, the person receives a video image, through a camera, and a schematic top sight view of the robot displacement in the room as information feed-back. In this mode, the mental workload of the operator can be reduced by activation of ultrasonic sensors that allow to avoid obstacles, in order that the human being needs only to control the navigation to the final goal. Finally, it is from this mode that has been implemented the human-like behaviour of visual anticipation on the steering.

Next, there are the *visual modes* for which the operator does not directly control the wheels, but the camera direction though which the robot is guided. So, there is a first mode where, if the camera moves, the mobile robot stays in the same navigation angle, and when the camera stops to move in a particular direction, the robot goes in this direction. And a second mode, where the mental workload of the human being can also be reduced, by using a tracking function of the camera that allows to automatically control the navigation by tracking a specific object of the environment.

Finally, we have the less heavy control mode for the mental workload, categorised as *automatic navigation mode*. In this mode, the operator has only to point out an area on the schematic top sight view of the room. Following that, the programme computes the best trajectory that the robot will follow autonomously until the point indicated automatically. However, it is important to note that despite the low cognitive cost of this mode, we have not recorded a better performance compared with the precedent semiautonomous modes. This clearly shows the necessity to continue our research on the shared control modes and particularly the ones based on the human-like behaviour, because they seem to give the best general performance between efficacy and cognitive effort.

VI – Research of the appropriation level of the robotics arm.

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, little has actually been researched on human efforts made to adapting oneself to machines.

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 robotics 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-personnal 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 [16]. Besides, this body schema appears to be relatively dynamic because its outline would be distorted by the use of tools [17]. Thus, by utilising 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 robotics arm, which would thus be proof of appropriation.

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 centred 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 on the left arm of the subjects and on 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 was the training stage in which the teleoperator, like all humans, evaluated the range capacity of the robotics 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 robotics 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 ?”.

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 5 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 < .02].

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, which represents the “P” ratio of the robot (Pr) to that of the human (Ph) 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 Pr/Ph ratios on all of the axes confirms the similarity between direct human performance and indirect human performance.

To control the validity of this data, an experiment identical to the last one was carried out by asking to subjects 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 the robot’s 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 (Pr) to that of the right-arm (Ph). And indeed, there is a statistically significant difference [F(3,24) = 3,68 ; p < .03] for the interaction test between Ph right and Pr left according to the experimental axes.

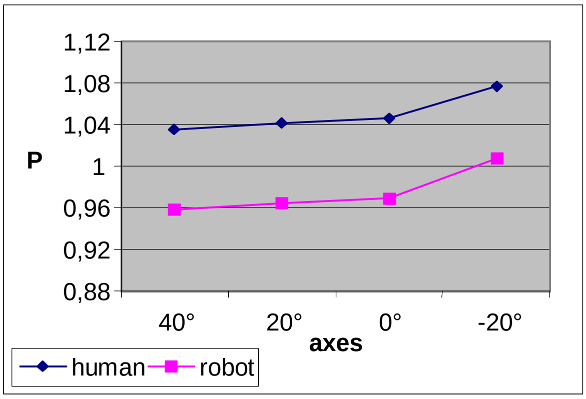

Figure 5 : Ratios P in the left arm situations

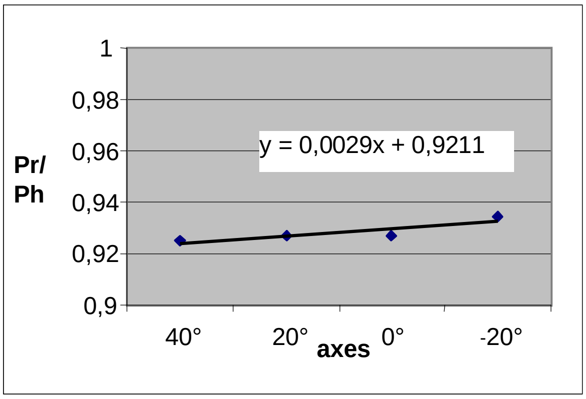

Figure 6 : Ratios P robot on P human

Discussion. The most important result of this study is to notice that the spatial anisotropy of the visuo-motor human system seems to be conserved when the human being acts indirectly on the environment, through a manipulator robot. This 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 visuo-motor architecture of a robotics teleoperated system by advocating the importance of making an anthropomorphic configuration to improve the human-machine co-operation.

VII – Conclusions.

These two studies show that it is pertinent to use neuroscientific works to make an optimal system of human-machine co-operation. Moreover, it is very important to note that this is true in different levels of the robotic system. Beginning with the functional level, we observed that the operator felt better when he piloted a robot with human-like reflex of visual anticipation on the steering. Then, when an anthropomorphic configuration has been reproduced for the visuo-manual relationship of the robot at the physical level, we note that the operator demonstrated a pattern of response similar to that seen in natural condition.

This strong retention of human characteristics during a remote-control action on the environment, shows that we cannot neglect the anatomo-functional properties of the human operator in the machine conception. This is particularly true of disabled peoples because having a morpho-functionality of their own, this neuroscientific approach will give them an easier utilisation and a better acceptability of this artificial assistance.

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