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The development of robot human-like behaviour for an efficient human-machine co-operation

Y. Rybarczyk[1,2], S. Galerne[1], P. Hoppenot[1], E. Colle[1], D. Mestre[2]

1. *CEMIF – Complex System Group – University of Evry, 40, rue du Pelvoux, 91020 Evry Cedex, France*
2. *Cognitive Neuroscience Center, CNRS UPR 9012, 31 Chemin Joseph Aiguier, 13402 Marseille Cedex 20*

e-mail : yrybarc | galerne | hoppenot | ecolle @cemif.univ-evry.fr | mestre@lnf.cnrs-mrs.fr

Abstract : *Robotics can provide technological solutions for improving the quality of life of disabled or elderly people. The main objective of this project is to give these people some independence. The use of a mobile base mounted arm allows for the restoration of some of the manipulatory functions lost by the person. Due to the cost of the final product, the robot is semiautonomous; that is to say, has some limitations in its environmental perception and decision-making capabilities. This lack of autonomy must be compensated for by human machine co-operation. One way to facilitate co-operation is to give the robot human-like behaviours when it executes automatic operations. This principle has been applied to the main functions needed for robot displacement, planning and navigation. This paper describes the approach we applied to develop a particular control method for the robot using a pan tilt camera. The method is composed of four steps : study of the human behaviour of interest, extraction of the pertinent features of the behaviour, implementation of the behaviour in automatic robot operation, and experimental evaluation.*

Key-words : *mobile robot-mounted arm, man-machine co-operation, human like behaviour.*

1. Introduction

People with disabilities and the elderly face daily challenges with respect to accessibility, job market integration, and medical assistance to name but a few. These difficulties have become the focus of some concern. Among the today's main life functions listed by the WHO (World Health Organisation) ([1]), manipulation is required for carrying, grasping, picking up, and moving objects. The primary objective of rehabilitation robotics is to either fully or partially restore the disabled user' s manipulative function by using a robot arm to interact between the user and the environment.

Different approaches have been presented in [2]. HANDY1 [3] and DeVAR [4], are table-mounted manipulators, which work in a known environment. Wheelchair-mounted manipulators, such as MANUS [5], allow operations in indoor and outdoor environments. Mobile robot mounted manipulators, such as MOVAID [6] and MOVAR [7], are the most complex but the most versatile configurations. Assistance systems currently available on the market usually require major transformations of the residence. On the other hand, semiautonomous mobile robots are a relevant configuration, due to their potential for minimising the required degree of home adaptation.

The success of rehabilitation robotics depends on respecting two key conditions. First, the system must not substitute, but rather compensate for the activity deficiency of people with disabilities. The second condition is the cost of providing this assistance. Cost effectiveness constraints imply the reduction of complexity and hence the robot' s autonomy. This loss of autonomy must be compensated for by close human machine co-operation. The degree to which the person intervenes during the task is variable. It can begin by taking part in perception or decision functions until totally remote controlling the system. The person successively builds strategies to carry out a task. A strategy can be seen as a succession of

control modes, which can be either automatic, if the robot executes operation autonomously, or manual if the robot is remotely controlled, or shared when operations are shared between man and machine. In this case, human-like behaviour of the robot might facilitates understanding by the user of how the robot operates during automatic operation. This approach allows for the building of specific strategies that are better adapted to the person's handicap, simplifying shifts in control modes.

Section 2 briefly presents the assistance system and the robots autonomous abilities. The ARPH (Assistance Robotics to Handicapped Person) project, promoted by the AFM (French Association against Myopathies), belongs to the third category. The human-like approach has been applied to the main functions needed for robot displacement, planning and navigation. The method is composed of four steps : study of the human behaviour of interest, extraction of the pertinent features of the behaviour, implementation of the behaviour in automatic robot operation, and experimental evaluation. Section 3 illustrates our approach in the case of a particular control mode of the robot using a pan tilt camera.

2. Assistance system architecture

Mobile robot

In order to limit costs, the robot has only limited perceptual capacities, consisting in an odometer, an ultrasonic ring and a camera. The odometer gives the position and the orientation versus angular rotation of the wheels. Ultrasonic sensors are used primarily for obstacle avoidance. The camera mounted on a pan and tilt base is a commercial device dedicated to general surveillance applications. It is used both as a perception device and a control device.

As a perception device, the camera has two roles : video feedback to the operator and autonomous localization of the mobile base. As a control device, the camera gives the direction to be followed by the robot. The camera emulates human displacement heuristics, by following the direction in which it is pointing.

Control station

The system architecture is shown in figure 1. The operator, through a control station, commands the robot described above. A keyboard, mouse or joystick can be used as a control device depending on the user's handicap. A screen displays information feedback : video images from the onboard camera, enhanced by virtual reality techniques (virtual aids superimposed onto the video image, robot position on a 2D flat plan, virtual camera point of view), ultrasonic measures, and robot operating indicators…

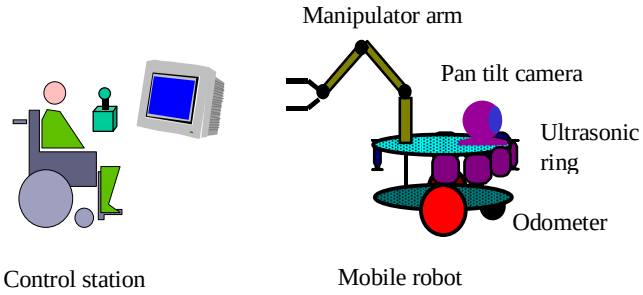


Fig.1 : *System architecture.*

3. Contributions of behavioural neuroscience to robot control

Driving remote-controlled vehicles involves numerous psychological problems. The *disembodied situation* of the operator summarises them. Indeed, unlike in a natural situation, the human being indirectly perceives and acts on the space in which the displacement is being carried out [8]. This situation causes two main difficulties for the operator.

Firstly, because the perception is performed through an interface device, the sensorial feedback is incomplete and biased. Generally, the integrity of sensorial informations is not present or is badly transmitted to the operator [9]. This sensorial deficiency is the first main difficulty encountered by the operator (i.e. the lack of information feedback, as compared to a more natural situation).

The second problem is a motor control disadvantage. Since the human operator acts through an interface device, there is a shift between the characteristics of human motor control and that of the actual mechanical system control. This shift occurs because the psychomotor effort of the operator is more important in a remote-control situation. The operator sends more conscious motor commands than he/she would do to carry out the same movement in a natural direct situation.

The suggested solution for reducing this *disembodied problem* is to implement human-like behaviour in the robots work. Indeed, the major difficulty met by an operator who acts on a semi-automatic system is to take the control back, because he generally doesn't understand how the system works during the automatic step [10]. Inversely, 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. 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 behavioural 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 behaviour.

4. Application for trajectory planning

Behavioural observations

In the framework of human-machine co-operation, the control is a shared between the human operator and the machine. Through human behavioural studies, this sharing has been realised 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 [11], must help him/her to anticipate the followed trajectory [12].

Behavioural studies in humans show that anticipatory reflexes are present in human locomotion [13] and automobile driving [14]. 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 [15].

Likewise, 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

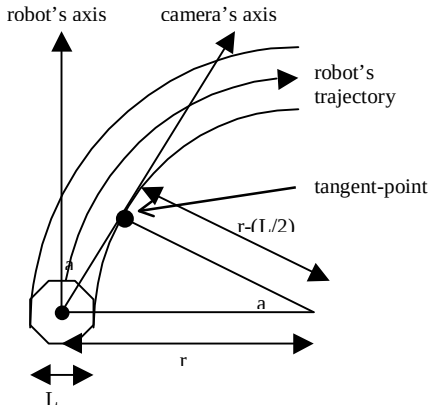
each bend. The direction of this point relative to the car's heading predicts the curvature of the road ahead [16]. In summary, a "go where you look" strategy seems to underlie steering along curved trajectories.

Experimental application

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.2).

Fig.2 : *Geometry of the tangent-point of the inside curve. The camera's 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.*

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



The experiment evaluate 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.

However, despite the fact that camera mobility can help the operator by providing visual information on this critical tangent-point, it is also possible that this mobility can disorient him. Consequently, to evaluate more precisely the potential perceptual advantage of the panning, as opposed to a possible disorienting problem, two other conditions have been tested.

Firstly, different gains of camera panning have been used. The equation of panning has been multiplied by a factor k of weight 1, ½ or 0. Then, the final equation is : **a = k(arc cos (1-(L/2)/r)).** Secondly, the pan efficiency has been evaluated by comparing a tilt angle condition in which the operator can see the front-end of the robot and a condition where he/she cannot.

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°. 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 : three independent groups of 5 subjects have passed the three main conditions (camera pan gain of 0, 1 and ½). Groups were independent to avoid a confounded learning effect. After a short trying session, each subject has realised eight testing sessions : four in which he saw the front of the robot and four in which he did not.

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.

Assumptions

Assumption 1 : performance should be better in the condition where the operator perceives the space through a mobile camera.

Assumption 2 : because camera movement is automatic, and consequently can disorient the operator, the mobile camera should be more efficient with a limited gain and a vision of the front of the vehicle.

Results

Figure 3 and figure 4 show the performance difference between each main condition. The average time for the execution time of the travel (fig.3) is significantly lower with the mobile camera, whatever the gain may be, 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 ($F[2, 117] = 29.8$; $p<.0001$) (fig.4), and the number of collisions ($F[2, 117] = 9$; $p<.0002$). However, there is no statistical difference in performance between the two gains (1 and ½) of the mobile camera.

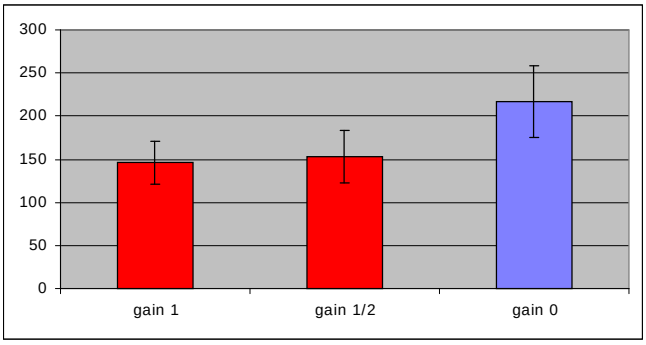


Fig.3 : *Average time for the execution of the travel.*

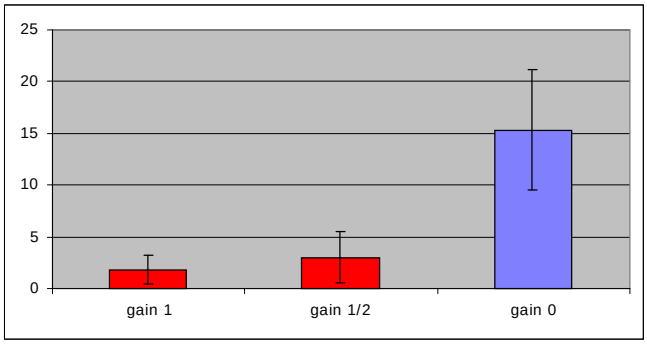


Fig.4 : *Average number of stops.*

The vision of the front of the vehicle gives no significant advantage in execution time of the travel and in the number stops. However, there is a significant advantage to seeing the front of the robot to avoid collisions with obstacles ($p<.02$).

Discussion

The latter result shows that it is better to see the front of the vehicle in order to avoid collisions with obstacles. A possible explanation for this is that when the operator can see the vehicle and the obstacle on the same picture, he can avoid it more easily, because he can tell exactly if the robot can pass or not.

Furthermore, main result of this experiment concerns the mobility of the camera. 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. 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, despite the fact that human beings have a specific gaze rotation angle in a direct situation, this angle is not necessarily the same in a remote-control situation, especially because the camera's field of view differs from a human's field of view.

To investigate these questions more precisely it will be necessary to carry out further experimental work, testing at least two other gains. A Gain of ¾ to know if the best pan angle is between gain 1 and ½, and a gain of ¼ to know if there is a conservation of the camera mobility advantage for a very limited pan gain.

The final goal would be to know if the major advantage of a mobile camera consists only of bringing visual motion information to the operator (directly related to the visual bases

of trajectory control), or really of giving more peripheral visual information on the inside of the trajectory to the operator (related to an enlargement of the functional visual field, [17]). To do this, the relationships between the camera pan gain and the width of the camera field of view and their effects on the quality of operator remote-control must be studied.

5. Conclusion

Enhancement of man-machine co-operation based on the observation of natural human behaviour, already used on robot planning and navigation tasks, has been showed on this driving control mode. Experimental results have underlined two main features : a moving camera depending on the robot trajectory and a little tilt angle allowing the seeing of the front of the vehicle. These features acting as a compensation for the reduced camera field of view have leaded to a better driving control with softer trajectories, less stop points and less collisions, finally a better confidence for the operator. In case of disabled people controlling a mobile robot with a mounted arm, this latter point constitutes a real advantage. Beyond this study, other control modes are going to be developed using this human-like behaviour method from driving to manipulation control tasks.

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