Space perception for tele-operation tasks

P. Hoppenot*, Y. Rybarczyk, D. Mestre**, E. Colle***
*LSC, University of Evry, hoppenot | ecolle @iup.univ-evry.fr
**LMP, University of Marseilles, rybar | mestre @laps.univ-mrs.fr

Abstract – In tele-operation tasks, for example with robotic systems, space perception and representation is a crucial issue. The operator and the machine are not in the same place. One way to make space perception and representation easier for the operator is to give him natural feedback information about the environment of the robot and the action done by the robot. A human-like conception of the robot helps to obtain this kind of space perception and representation. This paper deals with a manipulator arm embarked on a mobile base. Morpho-functional and morphological aspects are studied to show that anthropomorphic conception helps the operator in space representation.

Keywords: tele-operation, space perception and representation, robotics.

I. INTRODUCTION

The most important problem in tele-operation tasks comes from sensorial impoverishment because of the separation between the entity which controls the action (human being) and the entity which executes it (the machine). Fig. 1 illustrates tele-operation situation in which the human operator is far from the area where the action takes place.

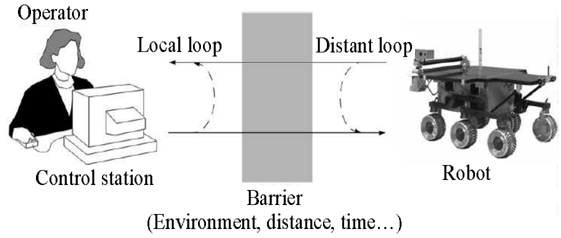

Fig. 1: Teleoperation situation (adapted from [FON01]).

The most common solution to solve the problem is to elaborate a man-machine co-operation. The central point is then task allocation ([GAI97]) or function allocation ([HOC00]) between man and machine. The initial idea was to compare the performances of man and machine for one task and to assign it to the agent with the best result ([FIT51]). Several critics have been formulated. The main pertinent one is that some tasks are totally realised by the machine, but the human operator keeps the responsibility of the global system. In some cases, this strategy where human being is out of the control loop leads to the abandon of automatic modes by the operator ([VAN94]). The notion of joint cognitive systems, introduced in [HOL83] and developed in [RAS94] and [WOO95], reveals that "the system must facilitate the appropriation of the system response by the operator" ([KAR95]). So, the problem is not only task allocation but interpretation of the behaviour of the system by the operator.

In normal situation, human being exploits a great diversity of sensorial information (visual, aural, tactile, vestibular…). In tele-operation situation, some of them are degraded or totally absent. Two of them are overexploited: vision and proprioception. Proprioceptive one is less used than visual one ([GRI97], [STA98]) even if recent works deal with haptic feedback ([COI02], [DUR03]).

This paper deals with video feedback, which deteriorates control performances ([SMI90]). That leads to difficulty to evaluate relative positions of objects and specially affects relative distance evaluation, due to visual field restriction ([MAS89]). Disparity and binocular parallax indices disappear in video image because of the projection ([CUT95], [REI96]). More, movement of the operator does not generate optic flow (sagittal displacement) or movement parallax (lateral displacement) ([BIN98], [COR96]). It is also impossible to determine the distance of an object only using its size.
So, reduction of spatial indices giving depth perception implies a reduction of performance in tele-operation situations ([FER01]).

II. CONTEXT AND OBJECTVES

The context of this paper is robotic assistance to disabled people. LSC (Complex System Laboratory) develops ARPH (Robotic Assistance to Person with Handicap) project since 1994 ([HOP02]). The objective is to give a part of autonomy to disabled people in daily life. A manipulator arm is embarked on a mobile base to restore, at least partially, the manipulation function.

In that specific context, the human operator wants to act by herself/himself. Because of her/his handicap, the operator can not realise the mission totally by herself/himself. The robot and the human operator have perception, decision and action capacities. Both must co-operate to achieve the desired mission, under the control of the person. The person has two main difficulties. The first one is perception of the distant scene, where the action takes place. The second one is perception of the actions of the robot in this scene. Both deal with feedback information and space perception and representation in the distant scene. One main issue of ARPH project is to give to the operator feedback information which can be easily understood.

This paper deals with human like conception of the robot to make distant scene and distant action perception and representation easier by the operator. Two aspects are taken into account. Morpho-functional aspect is developed for mobility by implementation of visuo-motor anticipation mechanisms. Morphological aspect is studied for manipulation function by positioning visual reference frame compared to grasping organ.

III. MORPHO-FUNCTIONAL ASPECT

A. Study presentation

In tele-operation, absence or bad restitution of certain types of perspective information constraints the operator to privilege certain sensorial modalities. Several studies have shown that visual modality is overexploited in tele-operation by comparison with natural situation ([TER90], [MES95]). But, even with this kind of feedback, performances decrease compared to natural perception of action space ([MAS89]). Two types of visual limits exist: temporal ones and spatial ones. In temporal point of view, works have shown that a delay up to 300 milliseconds involves great difficulties to control the system. Even without delay, indirect vision implies a lack of parallax ([COR96]) of optical flow ([GIB79], [WAR91]). In spatial point of view, limitation of visual field involves difficulty to evaluate distances and depth.

To palliate these difficulties of space perception and representation, visuo-motor anticipation seems to be a good behavioural solution. During a displacement, the axis of the gaze systematically anticipates the future trajectory. Indeed, in curve trajectories, head orientation, more precisely gaze direction, of the person is deviated in the inside of the trajectory. This would guide the trajectory by a systematic anticipation of the trajectory direction with an interval of 200 milliseconds ([GRA96]). A strategy like "I go where I look" and not "I look where I go" seems to be involved in that case ([LAN98]). It is the same behaviour to walk around an obstacle. This suggests that gaze orientation is guided using a step by step mechanism which predicts the new direction to follow ([PAT91]).

B. Experiment objective

The objective of the experiment is to test anticipation phenomenon to mobile base command. This base is a two driving wheel one. A PC is embarked on it, which communicates with a fixed control station through Internet. A pan-tilt camera is used as well as a feedback sensor than an actuator. Two visual anticipations are implemented on the system. In the first one, the operator drives the mobile base and the camera anticipates the movement depending on the command. This is a "I look where I go" strategy. In the second one, the operator controls directly the camera and the mobile base follows the direction of the camera. This is a "I go where I look" strategy. In reference to the works presented above ([LAN98]), the second strategy should be better than the first one.

C. Experiment results

Three command modes have been tested, two with anticipation, one without anticipation. This last mode corresponds to a fixed camera, aligned with the robot axis, and a manual control of the displacement. In the first visual anticipation mode, called "mobile base" mode, the operator controls the mobile base. Fig. 2 shows the orientation of the camera in function of the trajectory of the robot. The camera is oriented in the direction of the tangent point of the trajectory.

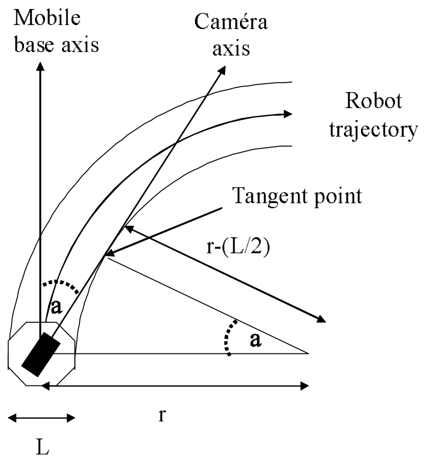

Fig. 2: Mobile base anticipation mode.

In the second visual anticipation mode, called "camera" mode, the operator controls the camera. Fig. 3 shows the orientation of the mobile base in function of the direction of the camera. The instant trajectory of the robot is the tangent straight line with circle centred on the obstacle. The radius of the circle depends on the radius of the robot.

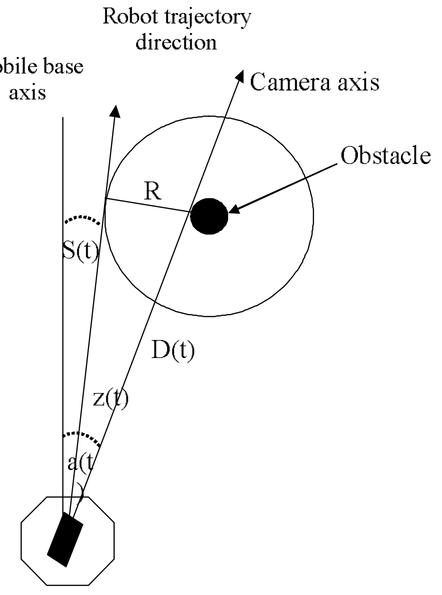

Fig. 3: Camera anticipation mode.

The hypothesis is that in "camera" control will be better than in "mobile base" mode. The "fixed" mode is used as a reference. The operator has to realise a slalom (Fig. 4). This is tested with two types of parameters: performance parameters (trajectory execution time, collision number, stop number) and behavioural parameters (trajectory smoothness, power law).

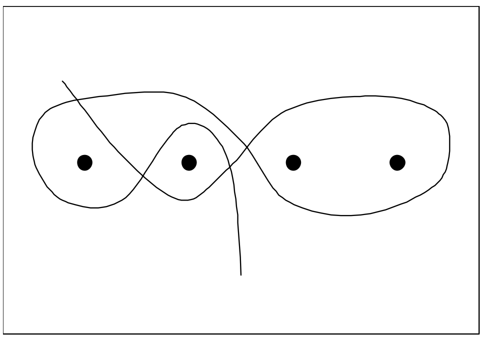

Fig. 4: Schematic representation of the trajectory.

About collisions (Fig. 5), anticipation conditions ("camera" mode plus "mobile base" mode) present significantly less collision than "fixed" mode ($p<0.01$). There is no significant difference between "camera" mode and "mobile base" mode.

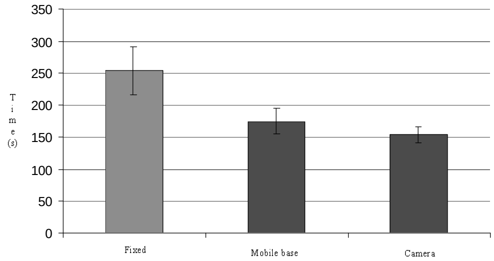

Fig. 5: Mean time of execution.

Concerning number of collisions (Fig. 6), anticipation condition have significantly less collisions than "fixed" condition ($p<0.03$). But there is no significant difference between "mobile base" mode and "fixed" mode. There is also no significant difference between "camera" mode and "mobile base" mode.

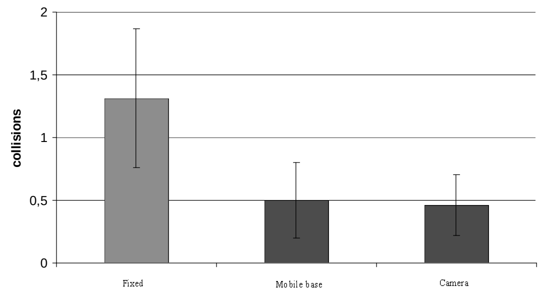

Fig. 6: Mean number of collisions.

About number of stops, both anticipation conditions are very significantly better than "fixed" condition.

Let see behavioural parameters. Fig. 7 shows a trajectory in anticipation condition. Fig. 8 shows a trajectory in "fixed" condition. The second one is more angular than the first one. [PER99] proposes a solution to quantify this. Number of occurrence of radius of curvature ($r=v/w$, v: linear speed, w: rotation speed) is represented in Fig. 9. X axis is expressed in logarithm of radius of curvature, Y axis is the occurrence percentages of these radius of curvature.

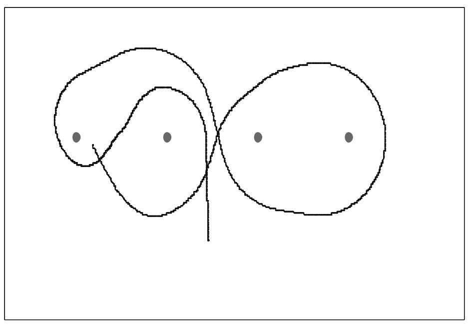

Fig. 7: Trajectory in anticipation mode.

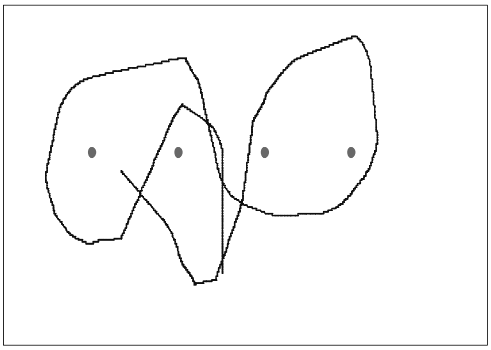

Fig. 8: Trajectory in "fixed" mode.

A small radius of curvature (log(r)<0) represents a small linear speed and big rotation speed, which corresponds to angular trajectory. An important radius of curvature (log(r)>0) represents a smooth trajectory. Fig. 9 shows an important occurrence of radius of curvature around log(r)=0 in all conditions. That corresponds to mean radius of curvature. But, around log(r)=-2, which corresponds to about only rotation, this number is significantly higher in "fixed" condition than in "mobile base" condition, which higher than in "camera" condition. So, anticipation conditions are batter than "fixed" condition, but also anthropomorphic condition ("camera") is better than non anthropomorphic condition ("mobile base").

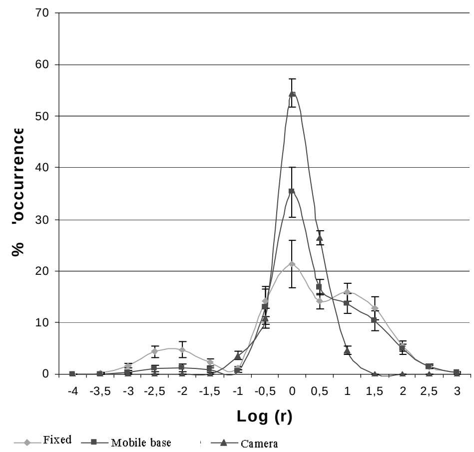

Fig. 9: Occurrence percentages of radius of curvature.

This propensity to smooth trajectories is generalised by human being in all movements, probably to minimise a cost function ([TOD98], [VIV95]). It is not limited to geometrical aspects but takes into account a relation between geometry (radius of curvature) and cinematic (linear speed). This kind of relation has been studied for example in writing gestures ([VIV85], [MAS92], [SOE86]). They follow the "power law" ([LAC83], [VIV91]). It says that instantaneous linear speed is proportional to the cube root of the radius of curvature. This law is not only effective in arm movements but also in human locomotion ([VIE01]). In logarithm representation, a 1/3 ratio appears between the two.

Results are very interesting. In "fixed" condition, correlation between linear speed and radius of curvature is not significant. The equation of the best fit line linking their logarithm is: y=0.01x+0. Conclusions are the same in "mobile base" condition. The equation of the best fit line in that case is: y=0.02x+y. Even if there was a significant correlation, the 1/3 ratio does not appears.

In "camera" mode, conclusions are very different. First of all, correlation between linear speed and radius of curvature is now significant (p<0.001). But more, Fig. 10 shows that a 1/3 ratio appears between the two in logarithm representation. In that mode, the natural relation between linear speed and radius of curvature exists.

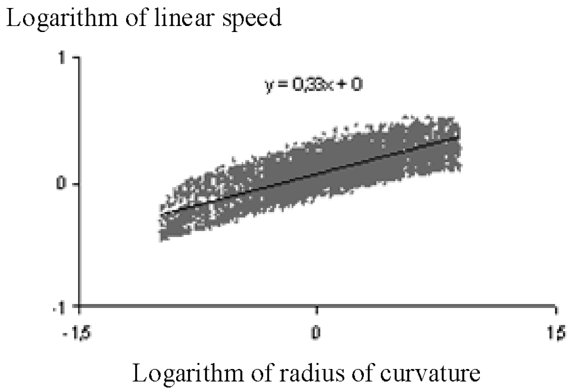

Fig. 10: Relation between logarithm of radius of curvature and logarithm of linear speed.

D. Discussion

Two kinds of parameters have been studied to compare the three control modes. Performance parameters (trajectory execution time, collision number, stop number) show that both visual anticipation modes ("camera" and "mobile base") gives better results than "fixed" mode.

Behavioural parameters (trajectory smoothness, power law) confirm the previous results. They also give more precision. The first parameter analyses smoothness and occurrence of radius of curvature. It shows that there is significantly less small radius of curvature, corresponding to pure rotation, in "camera" mode than in "mobile base" mode". The control is smoother in "camera" mode than in "mobile base" mode. The second parameter is the most interesting. It shows a natural control in "camera" mode, with respect to the power law, not present in "mobile base" mode. That means anthropomorphic condition ("camera" mode) gives easier distant scene and distant action perception and representation by the operator than non anthropomorphic condition ("mobile base" mode).

IV. MORPHOLOGICAL ASPECT

A. Study presentation

Space organisation has been studied from different points of view. From a psychophysical point of view, three concentric spaces are considered around the operator. Personal space corresponds to space in which objects can be manipulated by arm extension. Action space, about 30 meters, corresponds to a kind of relational space in which it is possible to communicate, to move quickly from one point to another or to exchange objects. Different sources are used to detect space according distance ([CUT97]).
From a neuropsychological point of view, near space and far space are distinguished. Some pathologies have been studied in which patients present neuropsychological disorders. Some of them can not have a representation of near space, other of far space ([COW99]).
From a neurophysiologic point of view, studies have shown that different cerebral areas are activated according to space involved for the action, peri-corporal one or extra-corporal one ([JEA97]).

This dichotomy in two or three spaces has no precise limit. Corporal scheme results from dynamic properties. [IRI96] shows that when a monkey uses a tool, its peri-corporal space extends to accessible space by this tool. In the case of peri-personal negligence, it is extended to stick dimension ([BER00]). In a tele-operation situation, the intervention field of the operator increase by the way of the mechanical tool. It could be possible to make the hypothesis that the same peri-corporal space extension of the operator exists including the tele-robot. But another characteristic of tele-operation situation is that no physical contact with the tool exists. That could disturb the visuo-tactile integration phenomena. Indeed, some works have shown that there is no peri-manual space extension in the case of physical discontinuity between the operator and a stick when the relation is passive ([MAR01]). In our case, the tele-operator is active but has no tactile feedback. This very particular context of tele-operation situation is original to study modulation of space representation.

B. Experiment objective

The objective of these experiments is to study if an anthropomorphic eye-arm relation on the tele-robot facilitates the control of the system. The way we choose to measure this facilitation is the appropriation degree of the system by the operator. Indeed, if the tele-robot enters the peri-personal space that proves that the operator has a good perception of the environment of the robot.

In [WAR87], a number Π is defined to characterise the ratio between a dimension of the human organism and an experimental variable associated to it. It is then possible to identify optimal contexts in which actions will be easier or efficient and, in the opposite, critical contexts in which actions will be more difficult. In the following experiments, object to catch are at a distance D which is compared with the length of the robotic arm, R. In this case, $\Pi=D/R$. If D exceeds R, it is impossible to catch the object. Π not only measures a simple geometrical space perception but representational capacities of the operator. Indeed, to estimate the distance for which the object is not reachable, the operator must transform absolute co-ordinates of the environment in relative coordinates referenced to the arm ([FIT78]).

C. Experiment results

In fact, the issue is to compare R and the maximal catching distance D_m evaluated by the operator. So, the more $\Pi_m=D_m/R$ is near to 1, the more the appropriation is effective. R is easy to estimate. For D_m, it is more difficult. 8 positions are defined according to R. 4 are lower than R, 4 are higher than R with 1 more centimetre in each variation: ±1cm, ±4cm, ±8cm, ±13cm. The subject must answer by "yes" or "no" to the following question: "Can you catch the object with a simple arm extension?". To obtain the threshold value, each position is proposed 10 times in the five directions (Fig. 11). Once the 80 responses are recorded, the threshold S corresponds to the same number of "yes" and "no" in each side of S ([BON86]).

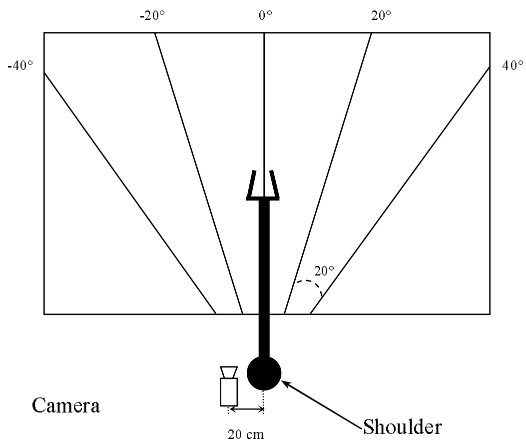

Fig. 11: Characteristic of experimental device

Two experimental configurations have been tested. In tele-operation condition, the camera is situated on the left of the mechanical arm, which corresponds to a right anthropomorphic condition. Operators have only indirect information of the scene through a camera feedback. In natural condition, operators are put in the same situation than the robotic arm. In that case, operators use their own perception systems.

The first major result of this experiment shows that there is no significant difference between tele-operated condition and human referenced condition. More, this identity is acquired very quickly, suggesting that reorganization of space representation is possible without extensive use of the tool ([BER00], [MAR01]).

With a more precise analyse, direction by direction, a second result appears. In two directions, 0° and 20°, Π_m is lower than 1 in robotic condition and nearly equals to 1 in natural condition. Two interpretations are possible: either the subject has over-estimated the distances or the length of the arm was underestimated. Several works have shown a tendency to underestimation of distances by subjects in monocular or limited field vision ([CRA70], [MOR84], [SER92], [BIN98], [COE97]). [FOG96] shows that peri-personal space is similar to circular or spherical arcs around the considered organ. But, contrarily to human arm, Manus arm, used in this experiment, presents a more important extension radius in 0° direction than on the sides. This bias explains Π_m variations. If only the numerator of Π_m is taken into account, the representation of extension space of the arm tends towards a circle like human arm. We can deduce that the operator had transposed her/his own arm representation on the robotic arm.

D. Discussion

This experiment shows that anthropomorphic position of the camera according to the arm implies space representation in tele-operation situation similar to natural situation. Once again, this facilitates distant scene and distant action perception and representation by the operator.

V. CONCLUSIONS AND PERSPECTIVES

Space perception and representation is a crucial issue in robotics. It is especially important in tele-operation modes in which the operator and the robotic system are not in the same place. The operator must perceive the scene where the action takes place and the action of the robot in this scene. One main issue of ARPH project is to give to the operator feedback information which can be easily understood. Human like conception is a good solution to help the user in space perception and representation.

A robotic arm deals with two aspects: mobility and object grasping. For both of them, this paper shows that anthropomorphic situations give better results than non anthropomorphic ones using different kinds of complementary parameters. That illustrates that anthropomorphic situations help the operator in tele-operation situation to have a good perception and representation of the scene where the robot acts and the action itself.

If the study of the mobility of the mobile base is important, more works have to be done about manipulation. Π ratio gives information on space representation by the user. Another experiment can be done with a comparison of performances of the operator with different positions of the camera, more or less anthropomorphic. Another idea could be to study performances with real arm displacement. The operator is then in perception-action situation which can give her/him other information to construct space representation.

VI. BIBLIOGRAPHY

[BER00] Berti, A., & Frassinetti, F. (2000). When far becomes near : remapping of space by tool use. *Journal of Cognitive Neuroscience, 12,* 415-420.

[BIN98] Bingham, G.P., & Pagano, C.C. (1998). The necessity of a perception-action approach to definite distance perception : monocular distance perception to guide reaching. *Journal of Experimental Psychology : Human Perception and Performance, 24,* 145-168.

[BON86] Bonnet, C. (1986). *Manuel pratique de psychophysique.* Paris : A. Colin.

[COE97] Coello, Y., & Grealy, M.A. (1997). Effect of size and frame of visual field on the accuracy of an aiming movement. *Perception, 26,* 287-300.

[COI02] Ph. Coiffet, & A. Kheddar (sous la direction) : "Téléopération et télérobotique", Chapitre 4: "Retours haptiques" (A. Kheddar) - Octobre 2002, Collection I2C Hermès – Lavoisier, ISBN 2-7462-0447-9.

[COR96] Cornilleau-Péres, V., & Gielen, C.C.A.M. (1996). Interactions between self-motion and depth perception in the processing of optic flow. *Trends in Neurosciences, 19,* 196-202.

[COW99] Cowey, A., Small, M., & Ellis, S. (1999). No abrupt change in visual hemineglect from near to far space. *Neuropsychologia, 37,* 1-6.

[CRA70] Crannell, C.W., & Peters, G. (1970). Monocular and binocular estimations of distance when knowledge of the relevant space is absent. *Journal of Psychology, 76,* 157-167.

[CUT95] Cutting, J.E., & Vishton, P.M. (1995). Perceiving layout and knowing distances : the integration, relative potency, and contextual use of different information about depth. In W. Epstein & S. Rogers (Eds), *Handbook of Perception and Cognition : Perception of Space and Motion.* San Diego, CA : Academic Press.

[CUT97] Cutting, J.E. (1997). How the eye measures reality and virtual reality. *Behavior Research Methods, Instrumentation and Computers, 29,* 29-36.

[DUR03] C. Duriez, C. Andriot et A. Kheddar : "Interactive haptics for virtual prototyping of deformable objects: snap-in tasks case" - EUROHAPTICS, July 5-9 2003, 2003 Dublin, Ireland.

[FER01] Ferrel, C., Orliaguet, J.P., Leifflen, D., Bard, C., & Fleury, M. (2001). Visual context and the control of movements through video display. *Human Factors, 43,* 56-65.

[FIT51] Fitts, P.M. (1951). *Human Engineering for an Effective Air Navigation and Traffic Control System.* Washington D.C. : National Research Council.

[FIT78] Fitch, H., & Turvey, M.T. (1978). On the control of activity : some remarks from an ecological point of view. In D. Landers & R. Christina (Eds), *Psychology of motor behavior and sport.* Urbana, IL : Human Kinetics Pub.

[FOG96] Fogassi, L., Gallese, V., Fadiga, L., Luppino, G., Matelli, M., & Rizzolatti, G. (1996). Coding of peripersonal space in inferior premotor cortex (area F4). *Journal of Neurophysiology, 76,* 141-157.

[FON01] Fong, T., & Thorpe, C. (2001). Vehicle teleoperation interface. *Autonomous Robots, 11,* 9-18.

[GAI97] Gaillard, J.P. (1997). *Psychologie de l'Homme au Travail. Les Relations Homme-Machine.* Paris : Dunod.

[GIB79] Gibson, J.J. (1979). *The ecological approach to visual perception.* Boston : Houghton Mifflin.

[GRA96] Grasso, R., Glasauer, S., Takei, Y., & Berthoz, A. (1996). The predictive brain : Anticipatory control of head direction for the steering of locomotion. *NeuroReport, 7,* 1170-1174.

[GRI97] Grimbergen, K.A. (1997). Minimally invasive surgery : human-machine aspects and engineering approaches. In T.B. Sheridan & T. Van Lunteren (Eds), *Perspectives on the Human Controller. Essays in honor of Henk, G. Stassen.* Mahwah, NJ : Lawrence Erlbaum Associates, INC, Publishers, 223-231.

[HOC00] Hoc, J.M. (2000). From human-machine interaction to human-machine cooperation. *Ergonomics, 43,* 833-843.

[HOL83] Hollnagel, E., & Woods, D.D. (1983). Cognitive systems engineering : new wine in new bottles. *International Journal of Man-Machine Studies, 18,* 583-600.

[HOP02] P. Hoppenot, E. Colle : "Mobile robot command by man-machine co-operation - Application to disabled and elderly people assistance" - Journal of Intelligent and Robotic Systems, vol. 34, n°3, pp. 235-252, July 2002.

[IRI96] Iriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurons. *Neuroreport, 7,* 2325-2330.

[JEA97] Jeannerod, M. (1997). *The Cognitive Neuroscience of Action.* Cambridge, MA: Blackwell.

[KAR95] Karsenty, L., & Brézillon, P. (1995). Coopération homme-machine et explication. *Le Travail Humain, 58,* 289-310.

[LAC83] Lacquaniti, F., Terzuolo, C., & Viviani, P. (1983). The law relating the kinematic and figural aspects of drawing movements. *Acta Psychological, 54,* 115-130.

[LAN98] Land, M.F. (1998). The visual control of steering. In L.R. Harris & K. Jenkin (Eds). *Vision and Action,* 163-180. Cambridge University Press.

[MAR01] Maravita, A., Husain, M., Clarke, K., & Driver, J. (2001). Reaching with a tool extends visual-tactile interactions into far space : evidence from cross-modal extinction. *Neuropsychologia, 39,* 580-585.

[MAS89] Massimo, M., & Sheridan, T. (1989). Variable force and visual feedback effects and teleoperator man/machine performance. *Nasa Conference on Space Telerobotics.* Pasadena.

[MAS92] Massey, J.T., Lurito, J.T., Pellizzer, G., & Georgopoulos, A.P. (1992). Three-dimensional drawings in isometric conditions : relation between geometry and kinematics. *Experimental Brain Research, 88,* 685-690.

[MES95] Mestre, D., & Péruch, P. (1995). Rapport final sur l'expérimentation "vision mobile" réalisée dans le cadre du contrat "Vision mobile et téléopération". *Cognition et Mouvement.*

[MOR84] Morrison, J.D., & Whiteside, T.C. (1984). Binocular cues in the perception of distance of a point source of light. *Perception, 13,* 555-566.

[PAT91] Patla, A.E., Prentice, S.D., Robinson, C., & Neufeld, J. (1991). Visual control of locomotion : Strategies for changing direction and for going over obstacles. *Journal of Experimental Psychology : Human Perception and Performance, 17,* 603-634.

[PER99] Péruch, P., & Mestre, D. (1999). Between desktop and head immersion : Functional visual field during vehicle control and navigation in virtual environments. *Presence, 8,* 54-64.

[RAS94] Rasmussen, J., Pejtersen, A.M., & Goodstein, L.P. (1994). *Cognitive Systems Engineering.* New-York : Wiley.

[REI96] Reinhardt-Rutland, A.H. (1996). Remote operation : a selective review of research into visual depth perception. *The Journal of General Psychology, 123,* 237-248.

[SER92] Servos, P., Goodale, M.A., & Jakobson, L.S. (1992). The role of binocular vision in prehension : a kinematic analysis. *Vision Research, 32,* 1513-1521.

[SMI90] Smith, T., & Smith, K. (1990). Human factors of workstation telepresence. In S. Griffin (Ed.), *Third Annual Workshop on SOAR'89,* 235-250. Houston, TX : NASA Conference Publication.

[SOE86] Soechting, J.F., Lacquaniti, F., & Terzuolo, C.A. (1986). Coordination of arm-movements in three-dimensional space. Sensorimotor mapping during drawing movement. *Neuroscience, 2,* 295-311.

[STA98] Stassen, H.G., Dankelman, J., & Grimbergen, C.A. (1998). Developments in minimally invasive surgery and interventional techniques. In *Proceedings of the 16th EAC on HDM and MC.* Kassel, Germany.

[TER90] Terré, C. (1990). *Conduite à Distance d'un Robot Mobile pour la Sécurité Civile : Approche Ergonomique.* Thèse, Université René-Descartes, Paris, France.

[TOD98] Todorov, E., & Jordan, M.I. (1998). Smoothness maximization along a predefined path accurately predicts the speed profiles of complex arm movements. *Journal of Neurophysiology, 80,* 696-714.

[VAN94] Vanderhaegen, F., Crevits, I, Debernard, S., & Millot, P (1994). Human-machine cooperation : toward an activity regulation assistance for different air-traffic control levels. *International Journal of Human-Computer Interaction, 6,* 65-104.

[VIE01] Vieilledent, S., Kerlirzin, Y., Dalbera, S., & Berthoz, A. (2001). Relationship between velocity and curvature of a human locomotor trajectory. *Neuroscience Letters, 305,* 65-69.

[VIV85] Viviani, P., & Cenzato, M. (1985). Segmentation and coupling in complex movements. *Journal of Experimental Psychology : Human Perception and Performance, 21,* 32-53.

[VIV91] Viviani, P., & Schneider, R. (1991). A developmental study of the relationship between geometry and kinematics in drawing movements. *Journal of Experimental Psychology : Human Perception and Performance, 17,* 198-218.

[VIV95] Viviani, P., & Flash, T. (1995). Minimum-jerk, two-thirds power law, and isochrony : converging approaches to movement planning. *Journal of Experimental Psychology Human Perception and Performance, 21,* 32-53.

[WAR87] Warren, W.H., & Whang, S. (1987). Visual guidance of walking through apertures : body-scaled information for affordances. *Journal of Experimental Psychology : Human Perception and Performance, 13,* 371-383.

[WAR91] Warren, W.H., Mestre, D., Blackwell, A.W., & Morris, M.W. (1991). Perception of circular heading from optic flow. *Journal of Experimental Psychology : Human Perception and Performance, 17,* 28-43.

[WOO95] Woods, D.D., & Roth, E.M. (1995). Symbolic AI computer simulations as tools for investigating the dynamics of joint cognitive systems. In J.M. Hoc, P.C. Cacciabus & E. Hollnagel (Eds), *Expertise and Technology : Cognition and Human-Computer Cooperation.* Hillsdale : Lawrence Erlbaum, 75-90.