ARPH: Comparison of a classical method and a method using man - machine collaboration to exploit the redundancy of the robotized assistant

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Abstract

Solutions kept in robotics of assistance are often very different from those used in industrial robotics. From the point of view of conception, it is appropriate to consider the person and the robotics of assistance as two elements belonging to a same complex system. The collaboration between these two entities becomes necessary and allows to set up innovative solutions. This paper tries to show on the example of the control of a mobile arm that it is possible to offer new algorithms by using the capacities of the person. We showed that a method of resolution of problems used in DAI gives an alternative in the mathematical models generally implemented to control a robot. This approach gives advantages. However the local character of resolution requires the presence of the upper level having a total vision of the process and able to take decisions. In robotics of assistance this role is played by the person as part of collaboration man - machine.

Résumé

Les solutions retenues en robotique d’assistance se démarquent souvent très fortement de celles employées en robotique industrielle. Du point de vue de la conception, il est pertinent de considérer la personne et le robot d’assistance comme deux éléments appartenant à un système complexe global. La coopération interne entre ces deux entités devient indispensable et permet de mettre en place des solutions innovantes. Ce papier tente de montrer sur l’exemple de la commande d’un bras mobile qu’il est possible de proposer de nouveaux algorithmes en s’appuyant sur les capacités de la personne. Nous avons montré qu’une méthode de résolution de problèmes utilisée en IAD offre une alternative aux modèles mathématiques généralement mis en œuvre pour commander un robot. Cette approche offre des avantages. Cependant le caractère local de la résolution nécessite la présence d’un niveau supérieur possédant une vision globale du processus et capable de décision. En robotique d’assistance ce rôle est joué par la personne dans le cadre de la coopération homme-machine.

keywords

Robotic assistance, redundancy, manipulability, multi-agents, mobile arm control.

1. Introduction

The disable people with a hard motor deficiency as the quadriplegics or myopathes can benefit from innovative technical helps to compensate their disability. Robotics is one of the disciplines that can bring solutions allowing to reduce the situation of disability in terms of mobility and manipulation. However the comprehension of help must take into account specific aspects of the domain of application. The first one is that this kind of help concerns only some thousand persons in France. Therefore, it is not possible to count on an effect of crow to make financially accessible the robotized if you do not considered helper in, at least, European space [1]. For the robotician, several, not exclusive, approaches of conception must be envisaged.

The first one is to reuse existent components as much as possible for propulsion, manipulation and perception. This option gives two important advantages which are the insurance of reliability of a commercial product and the existence of a network which assures maintenance.

The second approach tries to minimize the complexity of help during all cycle of R&D. This one can be reduced in a significant way by implicating the dependent person in the service given by robotized help. This man-machine cooperation has as principal role to distribute tasks with an adaptable and progressive degree of involvement of the person. Also to define the collaboration as well as possible and make it the most efficient, it is important to evaluate competences and capacities of both entities, human and machine, who can be considered to be partners.

The last approach which aims to enlarge the field of application and therefore to develop the effect of crow, consists in envisaging this help as being part of a group of services which objective is to help for keeping at home this dependent person. We suppose that potential services are functional replacement for mobility, manipulation and remote monitoring. From the point of view of services, it is possible to join means and therefore to reduce the costs.

Works introduced here are part of the second approach. As it was specified before, the precondition of a good collaboration requests to specify capacities and limits of every partner. The objective of this paper is to use as well as possible the robotized system constituted by Manus arm fixed on a mobile platform by exploiting the redundancy of the degrees of freedom of both subsystems and the collaboration between the man and the machine. The first section introduces a classical approach used in robotics. The second section represents an existent approach of DAI (Distributed Artificial intelligence) but which assumes collaboration with the person. These two approaches are then compared by simulating the execution of tasks as following straight line trajectory.

2. Redundancy use, robotic approach

Description and modeling of the mobile arm

The mobile manipulator used in *ARPH* project consists of a Manus arm manufactured by Exact Dynamics Company, mounted on a mobile platform powered by two independent drive wheels (Fig.1). Figure 2 present related frames used for the modeling of the mobile arm. Manus arm has six rotoides joints, with 3DOF for gripper positioning and 3DOF for gripper orientation. We adopt the following assumptions in modeling the mobile manipulator system. There is no slipping between the wheel and the floor. The platform can not move sidelong to maintain the non holonomic constraint. The manipulator is rigidly mounted on the platform.

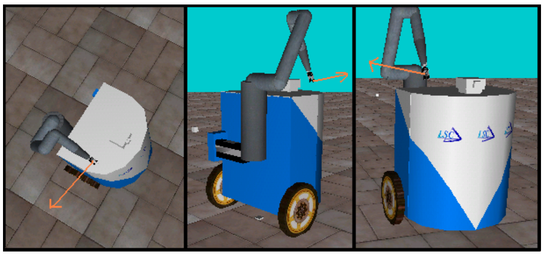

Fig 1. Mobile arm ARPH

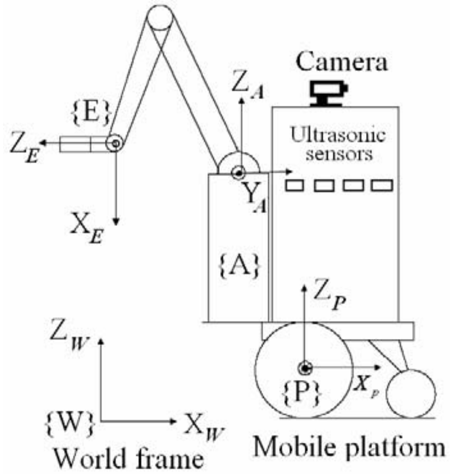

Fig 2. Mobile arm related frames

For kinematic modeling of the considered manipulator arm, we use the Denavit Hartenberg parameters[2]. The forward kinematics of a serial chain manipulator that relates the joint space and the task space variables is expressed by:

$$X_a = f_a(q_a), \tag{1}$$

where $X_a = [x_{a1}, x_{a2}, \cdots x_{am}]^T \in R^m$ is the vector of the task variables in *m*-dimensional task space, $q_a = [q_{a1}, q_{a2}, \cdots q_{an}]^T \in R^n$ is the vector of joint variables in the *n*-dimensional variables, called generalized coordinates, and f_a is the nonlinear function of the forward kinematics mapping.

Differentiating equation (1) with respect to time, we obtain a linear equation in velocity level:

$$\dot{X}_a = J_a(q_a)\dot{q}_a \,, \qquad (2)$$

where $\dot{X}_a$ is the task velocity vector, $\dot{q}_a$ is the joint velocity vector, and $J_a(q_a)$ is Jacobian matrix. The kinematic model of the platform is given by [3]:

$$\dot{q}_p = S(q_p)u_P \qquad (3)$$

where $S(q_p) = \begin{bmatrix} \cos(\theta_p) & 0 \\ \sin(\theta_p) & 0 \\ 0 & 1 \end{bmatrix}$ where $u_P = [v, \omega]^T$, v and ω are the linear and angular velocities of the platform, respectively.

The forward kinematic model of the mobile manipulator may be expressed in the following form

$$X = f(q_p,\ q_a) \,, \qquad (4)$$

where q_p is the generalized coordinates of the mobile platform and q_a represents joint variables of the arm defined above.

Thus, the configuration of the mobile manipulator is defined by the N generalized coordinates ($N=n+3$):

$$q = [q_p^T, q_a^T]^T = [x_p, y_p, q_p, q_{a1}, \ldots, q_{an}]^T \qquad (5)$$

The instantaneous kinematics model of the mobile arm is given by:

$$\dot{X} = J(q)\dot{q}, \qquad (6)$$

With $J(q) = \dfrac{\partial f}{\partial q}$.

Manipulability measure

Manipulability concept was originally introduced by Yoshikawa ([4], [5]) for manipulator arms to denote the measure for the ability of a manipulator to move in certain directions. The set of all end-effector velocities that are realizable by joint velocities such that the Euclidean norm of $\dot{q}_a$, $\|\dot{q}_a\| = (\dot{q}_{a1}^2 + \dot{q}_{a2}^2 + \cdots \dot{q}_{an}^2)^{1/2}$, satisfies $\|\dot{q}_a\| \le 1$, is an ellipsoid in m-dimensional Euclidean space. This ellipsoid represents an ability of manipulation. It is called the manipulability ellipsoid.

One of the representative measures of manipulation derived for the manipulability ellipsoid is:

$$w = \sqrt{\det(J_a(q_a)J_a^T(q_a))} \,, \qquad (7)$$

In the case of non redundant manipulators (n $=m$), the measure w is reduced to $w = \left|\det(J_a(q_a))\right|$.

Control scheme of the mobile arm

The redundancy of mobile manipulators plays an important role increasing their flexibility and versatility. Based on manipulability measure *w*, a control algorithm for utilizing the redundancy is given in this section.

Whitney [6] first proposed the use of the pseudo-inverse of the manipulator Jacobian to determine the minimum norm solution for the joint rates of a serial chain manipulator that can give a desired end-effector velocity. A weighted pseudo-inverse solution approach is also possible to take into account different capabilities of different joints as discussed in [7]. A variant of this approach includes the superposition of the null space component of the Jacobian on the minimum norm solution to optimize a secondary objective function [8], [9].

The same idea can be extended to the case of non holonomic mobile manipulator as expressed by the following equation:

$$u = \bar{J}^{+}\dot{X}_{d} + (I - \bar{J}^{+}\bar{J})Z, \qquad (8)$$

where Z is a (N-1)-dimensional arbitrary vector.

The solution of the system is composed of a particular solution $\bar{J}^{+}\dot{X}_{d}$ that minimizes $|u|$ and of a homogeneous solution $(I - \bar{J}^{+}\bar{J})Z$ belonging to the null space $N(\bar{J})$. These last additional components by definition do not affect the satisfaction of the task and can be used for other purposes. This is why the null space is sometimes called the redundant space in robotics.

Z vector can be exploited to locally minimize a scalar criterion. Using the same idea, Bayle [10] proposed the following scheme:

$$u = \bar{J}^{+}\dot{X}_{d} - (I - \bar{J}^{+}\bar{J})M^{T}W\left(\frac{\partial P}{\partial q}\right)^{T}, \qquad (9)$$

where $\dot{X}_{d}$ is the vector of desired task, *W a* positive weighting matrix and *P(q)* is the objective function depending on the configuration of the manipulator arm.

3. Exploiting redundancy, multi agent approach

The general method seen above to control a mobile arm consists in calculating the geometrical models and instantaneous kinematics model. This approach produces good results for repetitive tasks in known environments, what does not correspond to the conditions of use in robotics of service to the person for which the domicile is not absolutely known. Besides, in general, models are calculated off line and are unable to fit to modifications of the machine, a problem with one of the joint of the arm for example, without developing specific modes for breakdown treatment. The possibility of giving a « minimum service» in spite of waiting the repairering is an important element of the quality of assistive robotics. Distributed artificial intelligence ([11], [12]) offers methods of resolution for complex problems which allow freeing itself from the knowledge of the mathematical models of the robot ([13, [14, [15]). In our case, resolution is based on an multi agents architecture and is divided into two parts, one concerning the arm and the second one concerning the mobile platform. The redundancy of the system is exploited not only to ameliorate tolerance with certain breakdowns but also to give behaviors or configurations to the robot which make easier the appropriation of the machine by the person and then to facilitate collaboration.

Joint arm agents description

Principle

A reactive agent whose cognitive capacities, by definition, are very restricted [16, [17] is associated to each joint. Each agent accomplishes in parallel to others a local task without knowledge of actions of other agents. A global behavior can emerge from all local agents which satisfy the goal. Each agent calculates the position of the end-effector and tries then to make same this position with the goal. By an approach of type “virtual movement – check”, every agent moves by small local displacements to satisfy objective. If purpose is out of arm reachable space, each agent finish it’s movement by aligning the member it is controlling according to the vector $\overrightarrow{P_{Articulation}P_{Objectif}}$, the arm being then completely extended. Figure 3 shows an extension of MAS to 4 agents.

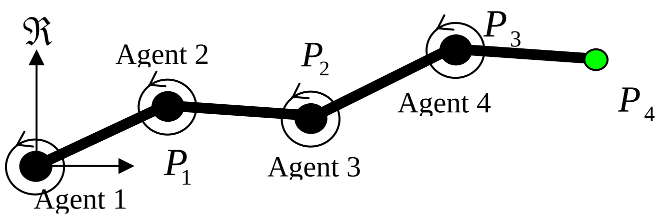

Fig 3. Arm with 4 couples « joint-agent »

Discussion

Each agent acts in an independent way without inter synchronization. The system becomes in certain limits, fault tolerant. Indeed, if one of the joint "breaks down" other agents are going to try to compensate fault. It is the autonomy of these agents whose local task is the minimization of a distance which allows this result. This local resolution of problem introduces of course known disadvantages but which are hard attenuated in a context of collaboration. The person brings her/his decision-making capacities which allow a global resolution.

Mobile platform agent description

It is an agent with global reflex character which has the capacity to enter a special cognitive mode. This mode allows to avoid blocking situations or to make easier the stabilization of the end organ when we couple subsystems, arm manipulator and mobile platform. Blocking situations could appear in real environment when we set on the obstacle avoidance module. For example, the arm could turn left during the mobile platform turn right. Then the end effector doesn't move and can't reach the goal. Cognitive mode is not implemented in the following simulations. We only keep the reflex behavior of the mobile platform which globally tries to align her moving direction with the arm orientation. In parallel, it tries to approach the goal to a comfortable distance according to arm reachable space.

4. COMPARISON OF THE METHODS BY SIMULATION

Simulation is aimed at comparing both approaches of control for the mobile arm. The task is to make the end effector following a straight line. Term MIM corresponds to the approach using the mathematical model, MAS is for the one using the agents. Figure 4 defines the position of the platform, table 1 shows initial conditions and table 2 shows parameters of simulation.

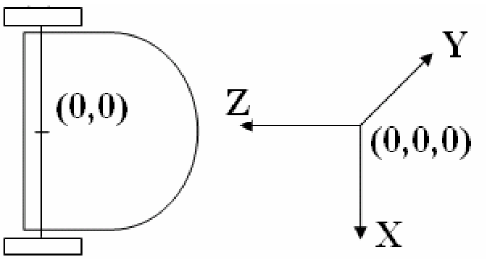

Fig 4. Initial position of mobile platform

TABLE I
INITITIAL CONDITIONS FOR SIMULATION

Object	**Initial value**
Mobile platform position	(0, 0, 0) cm
Arm joint n°1	270 degrés
Arm joint n°2	120 degrés
Arm joint n°3	-125 degrés
End tool position	(18, 79, -20) cm

TABLE II
SIMULATIONS PARAMETERS

Simulation steps	400
Sampling period	60 ms
Step displacement	(0.42 , 0.12 , 0) cm
Total duration	24 s

Fig 5 illustrates the trajectory followed by the platform for both approaches. With MIM the platform reaches a discontinuity point and then goes in motion back while MAS approach gives a regular trajectory.

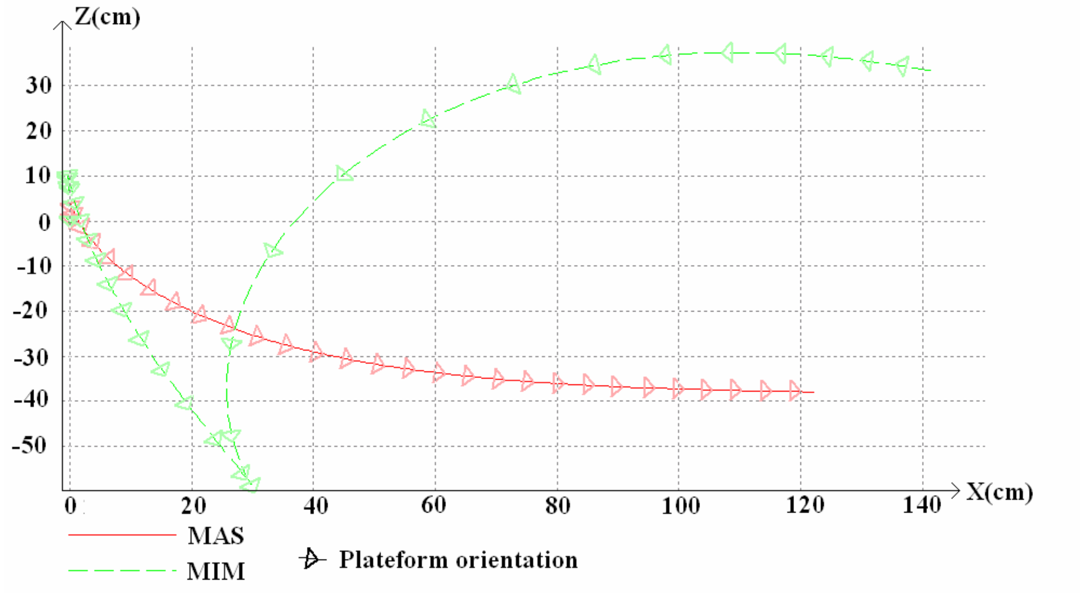

Fig 5. Mobile platform followed trajectories

Although it is not illustrated here, it is important to note that both approaches drive to a correct realization of task, the following of a straight line by the end effector.

Following simulation shows how the global system, arm manipulator on the mobile platform, acts in case of fault. As MIM is unable to manage this scenario, we only evaluate the MAS approach. Three situations were tested:

- Breakdown of shoulder (joint n°1) at 60°
- Breakdown of shoulder (joint n°1) at 30°
- Breakdown of arm (joint n°2) at 120°

Fault appears at t = 0. Figure 6 illustrates the displacement of the end effector along the x axis according to time.

The trajectory followed by the end tool remains a straight line in spite of the breakdown simulated at the beginning of task. Approach MAS allows, as planned, to compensate for the fault of one of the joint by exploiting redundancy. In effect in that case of simulation, joint n°1 can be partly compensated by the rotation of the mobile platform and joint n°2 by joint n°3.

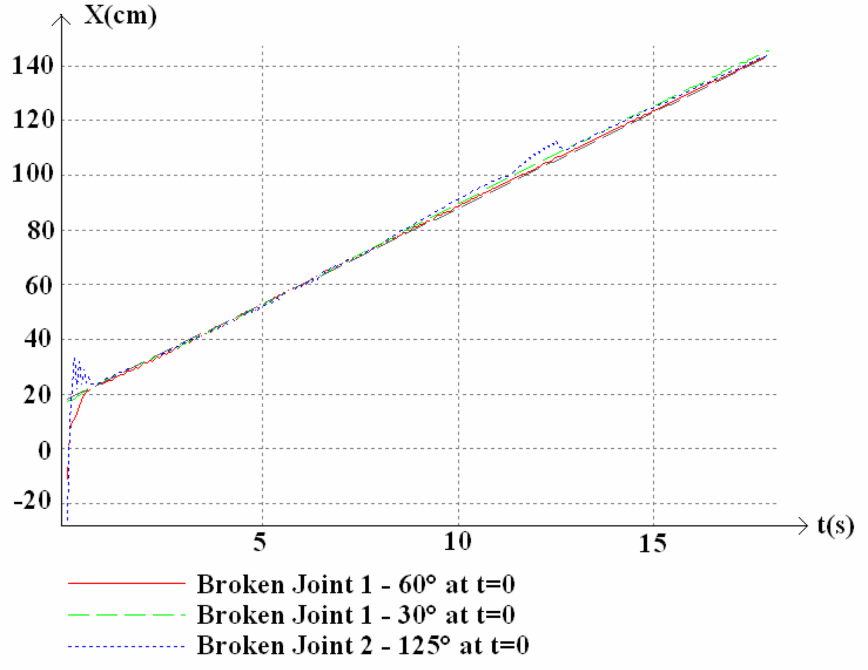

Fig 6. End tool trajectory along x axis

5. Conclusion

Solutions to be brought in robotics of assistance are often very different from those used in industrial robotics. From the point of view of design, without considerations of specific and critical criteria as the expense, it is appropriate to consider the person and the robot of assistance as two elements belonging to a global complex system. The collaboration between these two entities becomes necessary and allows setting up innovative solutions. In this paper we showed that methods of resolution of problems used in IAD give an alternative in the use of the mathematical models to control the mobile arm. Multi-agent approach offers a solution to this problem. This one, which gets closer to the human behavior, allows in our case to ameliorate tolerance fault with certain types of breakdown of the machine. This allows supporting what we could call a « minimum service ». It is necessary to say that reliability and expense are criterion considered critical by the users. However, multi-agent approach resolves problem on a local level and cannot be envisaged without the upper level able to have a global vision of situation and decision. In the case of the robotics of assistance, this level is assured by the person, which does not exist in industrial robotics.

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