Chapter 122
Cooperative Robots

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ABSTRACT

The interest in developing cooperative systems has increased due to the advantages they offer. Such systems can perform tasks that a single robot would be impossible to achieve. In this chapter, a summary of the cooperative robots's study, a classification of the type of grips, and path planning is presented. In addition, the properties and characteristics of the dynamic model, and the effects of torque and friction in contact tasks are shown. General considerations that should be made to analyze a cooperative system are introduced, and finally, the principle of orthogonalization, which separates the position and the force using a projection matrix which allows us to develop a control-observer scheme, is presented.

INTRODUCTION

The interest on developing cooperative systems has increased due to the advantages they offer against the single robot manipulators, since the cooperative systems can perform tasks which with a single robot would be impossible to achieve. In fact, in the industry many tasks are difficult or impossible to be executed by a single robot manipulator making it was necessary to use two or more manipulators in a cooperative way. Such tasks include handling heavy or large payloads, the assembly or disassembly of big or small pieces, and manipulating rigid or flexible objects.

The study of cooperative systems includes (Takase *et al.*, 1974) who implement the force/compliance control by using the back-drivability of actuators, without using force/torque's sensors. In (Nakano *et al.,* 1974) is proposed an approach of *master/slave forces control*, in order to coordinate two robot arms carrying an object cooperatively, and pointed out the necessity of force control for cooperative robots. In the work of (Fujii & Kurono, 1975) is used (Takase *et al.*, 1974) with the intention to adopt a concept of compliance control to coordinate multiple manipulators; defining a vector task respecting the object frame and controlled the fulfillment expressed in the same coordinate frame.

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Based on the robot manipulator's theoretical results, there was a breakthrough in the 80s. Examples include the studies of (Dauchez & Zapata, 1984) concerning the definition of the task's vectors in relation with the object to be manipulated. Force control's issues, such as hybrid position/force control, were explored by (Uchiyama *et al.*, 1987). (Tarn *et al.*, 1988) proposed new nonlinear control algorithms for multiple robot arms using the dynamics and control of the closed kinematic chain formed by the multi-robot and the object.

A strong theoretical background for the control of multi-robots has been formed, providing the basis for research on more advanced topics from the 1990s to present day. Critical issues of the cooperative systems have been studied, like how to parameterize constraint forces/moments of the object based on the dynamic model of the whole system. Actually, this parameterization leads to define the task's variables, it allowing to control simultaneously the trajectory of the object, the mechanical stresses (internal forces/moments) acting on the object, load sharing among the arms, and even the external forces/moments of the object. The key for solving these problems may be the decomposition force according to (Walker *et al.*, 1991). Another important problem is developing a geometrically clear parameterization of the internal forces and momentum acting-on the object; (Williams & Khatib, 1993) have given a solution to this modeling of internal forces in multi-grasp manipulation. About the intersection of work areas, which occurs when the robots operate cooperatively, in (Chiacchio *et al.*, 1996) was proposed a scheme to regulate the workspace of two robots transporting coordinately a rigid object holding it firmly. (Caccavele *et al.*, 1999) described a cooperative system that consists of two robot manipulators proposing complementary roles performed during the execution of tasks, proposing for one of the robots, a position control and the other one a force/torque control with feedback, in order to reduce uncertainty in planning tasks.

In (Tinós *et al.*, 2002) is studied how increases dynamic load when working with cooperative manipulators, which is one of the most important advantages offered by such systems. In (Fonseca *et al.*, 2003) is developed a method of force/torque control taking into account the dynamics within the system by applying this control to a cooperative system consisting of two robot arms; this research is based-on (Pfeffer *et al.*, 1993) and (Woong & Beom, 1999).

Several cooperative control schemes based on the requested parameterization have been designed, including *motion control* and force-impedance/compliance control. Other approaches include adaptive control, kinematic control, task-space regulation, joint-space control, and coordinated control.

Generally, tasks performed by cooperative systems can be classified as: human-human, human-robot and robot-robot cooperative tasks. For a *robot-robot cooperative system*, performing a task is necessary to study the characteristics of the assignment performed by humans, which allows us to model and reproduce the interactions between *human-robot system* and *robot-robot system*. An example of cooperative tasks performed by the *human-robot system* is the medical applications, where a robotic system can assist the physician in a microsurgery which requires a fine manipulation and the surgeon's experience, Figure 1. In medical application, for safe and firm and handling a force/position control is used.

It should be noted when performing cooperative tasks between robot manipulators and human must be internal and external sensors, in order to avoid the user may suffer physical damage. Importantly, the tasks where it needed human intervention are applications where human qualities are needed, such as: skill, intelligence and judgment. The *robot-robot cooperative tasks* have a wide range of application in industry and used to transport materials that exceed the capacity of a single robot, the assembly and disassembly of products, the overall system performance, etc. being the main disadvantage of cooperative systems a considerable increase in the complexity of planning, control and execution of tasks, Figure 2.