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AUTONOMOUS DEXTEROUS END-EFFECTORS FOR SPACE ROBOTICS[1]

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Abstract

This paper summarizes the development of a knowledge-based controller for the Belgrade/USC robot hand, a five-fingered end effector designed for maximum autonomy. The biological principles of the hand and its architecture are presented. The conceptual and software aspects of the grasp selection system are discussed, including both the effects of the geometry of the target object and the task to be performed. The concluding section of the paper presents some current research issues.

1 Introduction

Grasping and manipulation of objects in space by robotic systems will probably require a blend of teleoperation and autonomy for a number of years. However, the difficulties associated with placement of cameras and other sensors suggest that the robotic end-effectors used in unstructured environments be as autonomous as possible. Our group at USC, in collaboration with the University of Belgrade, has been active for several years in the development of robot hands capable of mimicking some aspects of human prehensile behavior. We have concentrated on autonomous grasping. Hence, the hands we have designed have limited degrees of freedom as required only for grasping and not for finger manipulation. Within this limitation, it is our goal to imbue the control systems for these hands with sufficient intelligence to be able to grasp objects of arbitrary shape with the hand posture appropriate for a given task. This paper presents a brief summary of the major features of the hand design, with emphasis on the software aspects.

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2 Human grasping

Following the work of Jeannerod [6], it is known that the human hand preshapes to the geometry of the object being grasped during the approach trajectory. The actual hand posture (grasp mode) selection is accompanied by the selection of the grasp location on the object in such a way as to bring functionally effective forces to bear, insuring a stable grasp appropriate to the task at hand. A model of this process has been developed by Iberall and Arbib [1,4]. Groups of fingers move generally together as a *virtual finger* setting up the forces that will be applied in opposition to each other. They are functionally effective in the sense that the chosen grasp mode must satisfy multiple constraints acting in the task. A number of investigators have catalogued the basic grasp modes of the human hand [3,7]. The human perceptual, cognitive and motor systems process geometric information on the target object in the light of the goals of the grasp and with a vast data bank of past experience to obtain the proper grasp mode. In [5], Iberall and MacKenzie identify numerous constraints acting on this process, separating some of the more functional issues from the physical ones. The final configuration of fingers and the applied force are obtained from a blend of sensory feedback and knowledge. We have attempted to incorporate some aspects of this process in the design of our hand.

3 The Belgrade/USC hand

The Belgrade/USC hand is an anthropomorphic, five-fingered end effector. The first model of the hand is illustrated in Fig. 1. It has four articulated fingers and a thumb. The two distal finger joints are not individually controllable; they are connected by linkages in order to move similarly to human fingers during grasping as the fingers flex (a virtual finger). The thumb in Model I was rigid, but capable of rotation about an axis normal to the palm, to bring it into opposition with any of the other fingers. A unique feature of the hand is its autonomous shape adaptation. Three motors are mounted in the wrist structure to provide the external degrees of freedom. One motor moves the thumb, while the others move two fingers each as a virtual finger. The virtual finger drive is applied to each pair of fingers through a lever structure, such that if the motion of one real finger is inhibited, the second can continue to move, thus achieving shape adaptation without external control [2,13].

The structural design of Model II (to be completed in the Summer of 1989) is illustrated in Fig. 2. This model features a jointed thumb (and hence an additional drive motor) and fingers capable of spreading prior to grasping.

The consequence of this design is that the hand is well suited to autonomous grasping of objects of arbitrary shape; it is capable of preshaping; and is simple to control, since all the motors are located in the wrist structure. Touch sensors are located on the finger tips and on the palm, position sensors are embedded within the fingers. The hand is mounted on a Puma 560 robot.

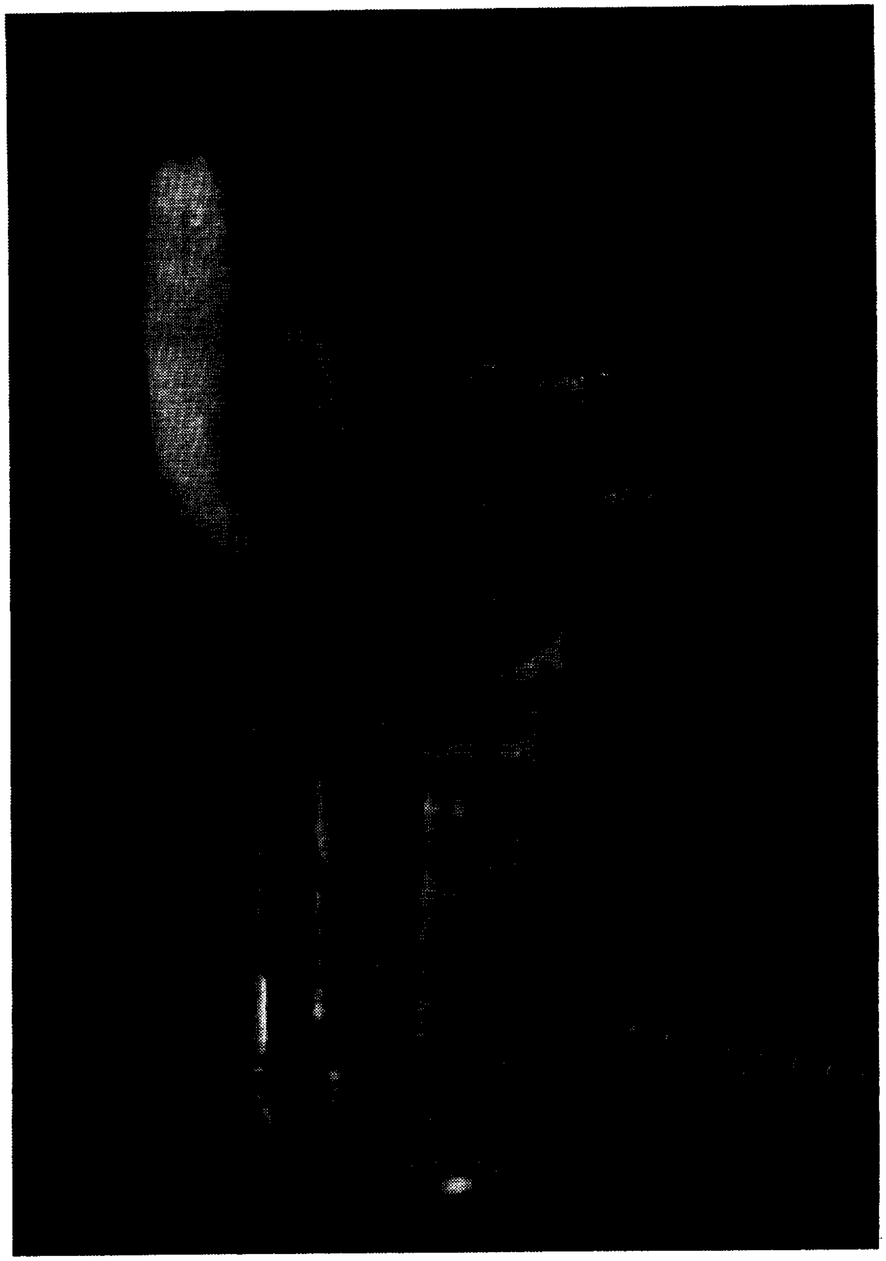

Figure 1. Belgrade/USC Model I hand.

4 Target geometry and grasp modes

The high-level grasp controller is knowledge-based, selecting a preshape on the basis of visual information on the target and a stored library of relationships between grasp modes and geometric primitives. The basic modules of the system are shown in Fig. 3. A camera provides the input to an image analysis system, which obtains a shape description using generalized cones [12], from which the name and parameters of a geometric primitive are deduced. The system includes such primitives as cone, cylinder, torus, etc. Given the geometric primitive and its dimensions, the system then obtains a list of all feasible grasp modes. This list is unranked; task information is needed to organize it. We have obtained the grasp modes by means of rules and tables [11]. We have also demonstrated a neural network approach to the problem [8, 10].

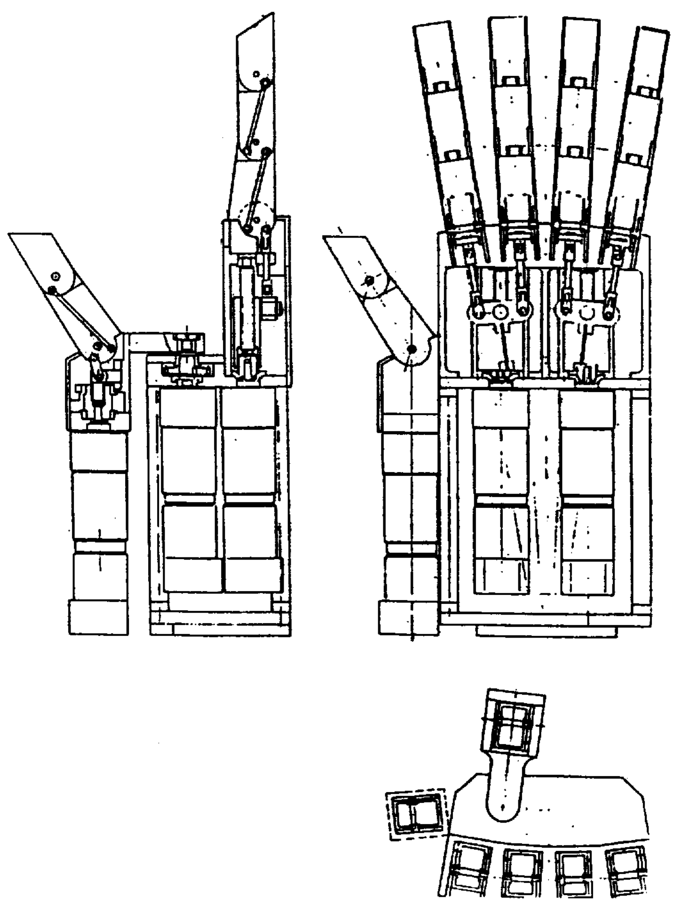

Figure 2. Belgrade-USC Model II hand.

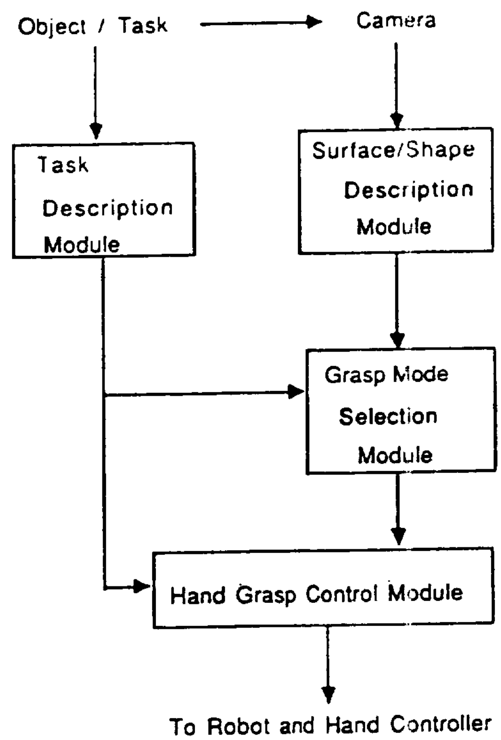

Figure 3. Grasp controller for Belgrade-USC hand.

5 Task information

Our recent work has focused on the question of selecting the preferred grasp mode from among all the permissible ones by using task information [9]. In order to restrict the size of the search space, we have restricted the domain to operations associated with simple assembly tasks, such as:

1. Grasp a wrench to tighten a nut
2. Grasp a hammer to drive the nail.
3. Pull handle to open the drawer.
4. Insert the pin into the hole.

The commands are parsed and the key elements (tool, action, part, context) are extracted and used as inputs to the task analyzer illustrated in Fig. 4. The nature of the action ("turn", "insert", etc.) and the type of tool are used with a functional database to determine the focus of the desired action. For example, using a wrench puts the focus on the ability to apply the maximum possible torque; inserting a pin requires the greatest possible ability to manipulate a small object in space; pick and place operations require a highly stable grasp. These action foci in turn make it possible to select which of a large number of heuristics concerning human grasping are appropriate to the task. Humans use such heuristics as "grasp the object as close to the center of gravity as possible" for some tasks and "grasp the object near the end" for others. Using a wrench to tighten a nut requires a different grasp heuristic than picking up the wrench to place it in a given location. As illustrated in Fig. 4, once the heuristics are selected and ordered, they are used to produce a rank-ordered list of grasp modes. The highest ranked mode is selected and the hand is preshaped accordingly. The details of this process are described in [9].

Currently our object analyzer contains descriptions of 5 primitives (cylinder, cube, torus, sphere and cone). The functional object database contains descriptions of 7 objects (wrench, screwdriver, hammer, nut, pin, handle and cylinder) as well as type of tool, center of gravity, function and other information. The task analyzer contains 72 production rules, 14 heuristics and 2 meta-heuristics (used to order the heuristics). The Model I hand is capable of 4 grasp modes (power grasp, hook grip, pulp pinch and lateral pinch). Additional modes usually associated with the human hand will be possible with Model II.

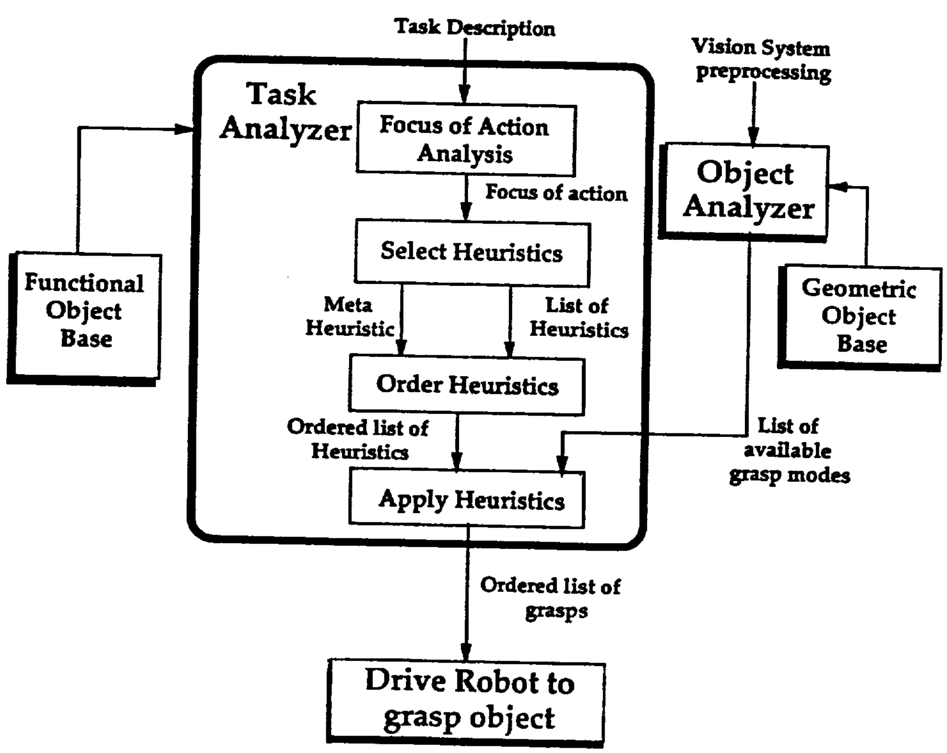

Figure 4. Task analyzer.

6 Current and future work

We have developed a knowledge based approach to reasoning about grasping from a task description, and used it succesfully to obtain grasp modes for a robot hand. The attributes of the task and knowledge about actions, objects and geometry have enabled us to rank order feasible grasps in order of quality.

Much work remains to be done to extend the functional object base and to broaden the task descriptions and attributes. We also plan to add slippage sensing to the hand and to include surface friction and estimated object weight into the system.

We believe that the approach to autonomous grasping described here, where both task and object geometry are considered in the determination of a grasp, offers great potential for space applications.

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