INTRODUCTION

Fast moving microprocessor technology leading to low-cost, highly capable microcomputer systems has been a key element in a research program aimed at examining the practicality of using a robot arm to assist the physically handicapped. A particularly critical need exists for the high spinal cord injured person for devices that increase self-care and independence for long periods of the day. Such individuals with total loss of upper and lower limb function represent one of the areas of greatest need in rehabilitation engineering. A research program at the Applied Physics Laboratory of The Johns Hopkins University has been underway since 1974 to examine the applicability of robotics to the solution of this problem. The program, sponsored by the Veterans Administration, has now reached the stage of clinical testing at Spinal Cord Injury Centers at VA Medical Centers in Richmond, Virginia, and Cleveland, Ohio.

Early in this program, visits were made to patients in Spinal Cord Injury Centers to determine the priority of needs that must be met by this equipment. Some of the important needs identified included self-feeding, management of a variety of reading materials, use of a telephone, use of a typewriter including insertion and removal of a sheet of paper, various hygiene and personal needs, and vocational capability such as the use of a personal computer.

Two approaches offer possible solution to these needs. One approach, that of designing specific devices to address each of the needs, leads to independent mechanical devices for each requirement. The cost and maintenance of such devices are significant factors to be considered prior to their purchase. Operation of more than one such device in a given work area is usually difficult or impossible.

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because there is no integration of the mechanical design of different subsystems, i.e., a typical electromechanical magazine reading machine is so large and bulky that it precludes using other devices within reach of the spinal cord injured patient. The alternative approach, a single multipurpose device such as a robot, promises of accomplishing many of the required tasks within a reasonable work area, and its motion flexibility will enable it to handle a variety of needed tasks.

**ROBOT FUNCTIONAL REQUIREMENTS FOR THE SPINAL CORD INJURED PATIENT**

In the more severe spinal cord injured cases, individuals are left with little or no functional capability of the hands and arms. The basic function of the robot, therefore, is to provide a substitute for these lost manipulative capabilities. Since the ranges of motions, speed, force capability, and controllability of the human arm clearly span a very wide dynamic range, compromises must be made in the selection of parameters for the robot for this human interface application.

An important factor that may distinguish a robot for human interface applications from one for industrial applications is the safety consideration. In many industrial applications, for example, the robot needs to perform at high force levels and with responsiveness, but is normally operating in an environment in which human beings are not permitted within range during robot activation. For medical applications such as discussed herein, the robot must, of necessity, be physically in close proximity to the user and yet must not cause any safety hazards in the event of a computer or other malfunction. This safety requirement clearly limits the forces and speed of motion to a level tolerable by the disabled person. Force levels of one or two pounds and maximum motion velocities of less than 10 cm per second are typical of safe values for a device operating in close proximity to a human being. The ability to reliably stop the robot while in its programmed mode is an important parameter to include in the design of the system.

The range of motions should ideally be several meters with a precision of a few millimeters. Another major consideration is whether the robot should be mobile and placed on a wheelchair with the user, or be stationary and placed on a fixed work table. Early models of robots examined in the mid-70's included both mobile (1, 2, 3) and work table models (4, 5, 6). The research team at JHU/APL elected to go with the work table arrangement (6) because the size, bulk, and weight of a wheelchair-mounted system was judged unacceptable to the user. This judgment appears to be confirmed by the lack of any