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A Survey of Robotics in Rehabilitation Applications

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A Survey of Robotics in Rehabilitation Applications.

Abstract

The purpose of this report is a study of published literature and the identification of basic concepts with emphasis on the rehabilitation area.

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Contents

1. Introduction

The application of robotics in the rehabilitation area is meant to help disabled regain independence or to restore functions lost. Several approaches, however, are also concerning prevocational training and education for people born disabled. One of the main reasons of introducing robotics is the anticipated impact on the self esteem for disabled who have relied heavily on other people in accomplishing daily tasks. Both in a home environment, in institutions and in vocational settings the manipulating robot, perhaps mobile, has a great potential of changing daily life for the disabled. Another area attracting much interest is the concept of a transport robot combining a stretcher and a wheelchair, thus enabling disabled to move more freely and to make it possible to get out of bed without help.

Advances in general robotics have initiated several projects within the rehabilitation area primarily aiming at manipulation of objects in a fairly structured environment. Reports from pilot studies in the area of manipulation have been reported as early as in 1980. The level of development and the complexity differ between different projects and the cost acceptance is an important factor not to be neglected. A spin off result from the development within industrial robotics is the concept of a personal robot, being somewhat simpler and thus cheaper than the robots that have been used until now. Considering the new materials being introduced the personal robot could be used extensively for health care applications, especially combined with new interfaces for communication with a controlling computer. As the disabled, being considered to use a robot system, have severe difficulties in communicating with a computer the developed methods for human interaction could also be of importance in wider applications of robotics. The ergonomic requirements also lead to research areas that are generally applicable.

This literature study has been combined with preliminary tests of a personal robot that could be used as a rehabilitative robot, but evaluation with potential users has not been conducted (Ruijter, 1988). In Sweden clinical evaluations are made with the same type of robot at the hospital in Skövde in a project sponsored by "Svenska Handikappinstitutet". This report is organized as follows: Chapter 2 presents a number of surveys done within the rehabilitation field, Chapter 3 gives the outline of development in known projects, Chapter 4 describes some known major projects in different areas and finally Chapter 5 presents some special projects that have been reported to give a perspective of other concepts than the prevailing. The references are listed in Chapter 6.

2. Surveys

A number of surveys have been done to investigate the potential application areas for robotics in the health care sector. Especially the rehabilitation area has been of great interest for introduction of technical aids based on the development of robots.

The most recent survey conducted has been a 12 month contract awarded to Fulmer Research Limited by the Department of Trade and Industry, United Kingdom. The report is not publically available at present but preliminary results have been reported in the proceedings of the First International Workshop on Robotic Applications in Medical and Health Care held in Ottawa, Canada (Finlay, 1988). The study was divided into five broad areas with rehabilitation being one of them. Several concepts were found in this area: work stations for the disabled, aids to daily living, prosthetics and orthotics, artificial organs, aids for the disabled living at home, aids for the visually handicapped and occupational therapy, but research can not be supported for all areas as some applications are considered to be too specialized. Although three concepts have been given priority: a fetch and carry robot for the disabled and elderly, a patient handling robot for use in hospitals and surgery assistant robots, the chosen medical robots for further development are not being used extensively within the health care field at present. Exceptions can be found, whole-body tomography scanners and a few specialized surgical devices, but most equipment is on a prototype stage. The research effort in the rehabilitation area is growing however, and programmes in different areas are reported in the U.S., Canada, Europe and Japan.

Several reasons can be found to explain the reluctance to use robotics in health care. The safety considerations with people that are frequently unable to take avoiding action if the robot should develop a fault is one aspect. Another is the legal liability for consequential injury and perhaps most important is the supposed psychological attitude of patients. A reason more difficult to justify is the difference between engineering and medicine, a more efficient mechanism for transfer of technology into medicine becomes increasingly important as technical aids become more common in the health care field.

A monograph covering the development of robotics in the rehabilitation area with emphasis on Europe and North America has been presented by the World Rehabilitation Fund (Foulds, 1986). An attempt has been made to discuss the factors involved in successful use of manipulators and several projects mainly addressing the work station concept are described. Development in close cooperation with the future users is stressed as there is a major difference in approach when designing systems comparing engineers and professionals in the rehabilitation field. In addition there is supposed to be a maximum rate of complexity versus economy giving a perspective on development of highly complex systems. The different degrees of complexity needed for accomplishing tasks of varying levels are also emphasised.

Another survey has been reported in connection with the project at the Neil Squire Foundation in Canada (Birch, 1986). Finally a survey of potential users of robotic aid systems has been made at the Royal National Hospital for Rheumatic Disease and Bath Institute of Medical Engineering in England (Clay et al., 1985).

3. Directions of Development

Many projects are based on product development and incorporate commercially available products but there are also programmes with research topics that are being addressed in industrial robotics. The devices that are custom made for applications in the medical field make the products considerably more expensive and in the long run joint ventures with other application areas will probably be necessary. It is difficult to make a statement about whether product development or research is to be preferred as the impact of robotics on rehabilitation and the health sector in general is depending on clinical evaluations and prototypes have to be constructed for testing by users. The acceptance of potential groups to use robots has not been one of the major issues until now as prototypes primarily have been built for functionality, but discussions are emerging on the need of social interaction and esthetics.

Several concepts can be identified in present work on robotics for the medical and health area. Manipulation is a broad concept including different approaches to restore lost functions to a disabled population. Mobile platforms to be used in moderately unstructured environments is another approach that has a potential of becoming important in many areas and connected with these two basic concepts is the interface necessary to make technical aids available to the different user categories. As solutions tend to be more complex much effort must be made to adapt the systems to users with little or no technical knowledge. Of course safety considerations are also of great importance when the systems are to be used with people in close proximity to the manipulator arm or the vehicle. Clinical evaluation is an emerging area considered to be important in order to determine the real value of systems in vocational and home situations.

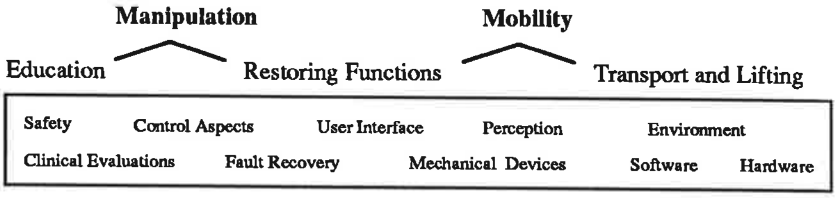

Figure 3.1 Basic concepts and related research areas

The two basic concepts within the rehabilitation field concerning robotics are manipulation and mobility and thus most research areas being addressed in industrial robotics are of interest, see fig. 3.1.

The most common approach is to use a manipulator to restore functions lost due to e.g. a spinal cord injury. The manipulator used in these applications is often integrated in what is commonly called a work station. The name might be a little misleading as functions dealing with feeding, tooth brushing and cooking are often included and the name desktop system has been suggested. Although there is no standardization of tasks to be completed, a first application can be identified, the use of a robot arm to move objects within a structured envelope that has been adapted to the needs of the user. The work station is primarily considered to be important in vocational settings but it could of course also be of great use in a home situation if proper fixtures are made. A second potential application based on manipulation is making it possible to have a robotic arm that is movable to different locations, thus enlarging the work space. The mobility can be achieved either through an autonomous vehicle with remote control or with e.g. a wheelchair that enables the user to keep eye contact with the arm. It is also possible to mount the robot on a track and get limited mobility in a stationary work station, as horizontal movements require a large envelope if the arm is to reach from the floor up to shelves and vertical displacement may be necessary in order to make the setup more flexible. There are no known products in the health care field concerning mobility and the area is still in a research phase. The research area has not been addressed in the same way as manipulation was earlier as there are no commercially available components that can be combined to a product. Thus research efforts have to be made in order to investigate the feasibility of incorporating enough information gathering systems to be able to ensure safety considerations. Especially the environment in which the device is to be used, both concerning manipulation tasks and mobile arms, has significance for the level of development and thus the cost of the system and precautions must be taken not to develop products that the users can not afford. Furthermore the environment has to be reasonably structured presently because use of sensor information is still an expensive solution to the control problem encountered in robotics. Accomplishing the tasks an able bodied user would complete using both his arms is another area of research, but the problem has not been addressed yet in rehabilitative robotics aiming at manipulators.

Another way of using the manipulator concept is to help people explore and experiment in a way that has not been possible to them earlier. These groups with people born disabled may have other expectations and could be able to use robotics in a different way. One possibility is to help very young children to develop as it is important for them to realise that they can interact with the environment physically. Another possibility is prevocational training enabling people with severe disabilities to become employed. The financial support offered may be of significance as an educational work station can be used by a larger group and the cost sensitivity may thus be reduced. The technical aspects are similar to the ones encountered when using the manipulator to restore lost functions but it might be necessary to make the system more sophisticated as it is to be used both in an educational and a vocational situation and thus has to be flexible.

A common concern for both types of work station is the user interface which has to be highly sophisticated as users have severe difficulties in communicating with the controlling computer. It is difficult to classify the various interfaces that have been considered but voice control combined with graphic screens and synthesised speech seems to be the most popular option. Of course almost any other way of interacting with computers has been considered in ongoing projects, examples range from joysticks, trackballs, head-position detectors and mouthsticks to custom made mechanical devices.

It might make more sense to classify the robots used for manipulating. One way of classifying manipulators is emphasising their origin, designs can be based on prostheses or orthoses, industrial robots or be custom made for rehabilitation purposes. Another way is describing the environment for usage which makes it possible to isolate designs such as stationary work stations, wheelchair-borne arms or mobile arms. A third way of classification could be the user groups a manipulator is intended for and the presumptive tasks to be achieved with the system.

The gripping function of the hand has been addressed earlier in prosthetics and orthosis research but there seems to be a new approach in robotics to further develop the fine movements required at manipulation. As this function is central to manipulation tasks much interest has been shown in integrating sensors and in planning motions. The increased computer power also allows development of preprogrammed routines to be called for special tasks requiring reflexes when done by an able bodied person. The ideal combination of direct, semi automatic and automatic control of the movements has not been found yet and extensive testing with prototypes will be necessary. The complexity and thus the ability of the manipulator, however, has to be balanced with support routines in order to keep the control burden at a reasonable level for the user.

The issues being addressed concerning manipulators to be used by disabled include the following ones:

- product development primarily and research secondarily
- control of the mechanical arm and mobile bases to mount the arm upon
- use within rehabilitation or habilitation
- adaption to an unstructured environment
- adaption of the user interface
- reducing complexity in manipulation by integration of automatic functions
- analysis of the setting the robot is to be used in
- the needed level of complexity to achieve standard tasks

As most programmes are directed towards manipulation tasks many of the issues mentioned above have been covered in published papers. Nevertheless, the different approaches to provide functional restoration often lead to specialization and several projects have concentrated on one area after initial feasibility studies as a common factor.

Another concept attracting much interest both in the health care field and in industrial applications is the possible utilization of a mobile base unit that could be used in a fairly unstructured environment. The possibility of equipping such a base with a manipulator is obvious but there are also other ways of using it. Patient transport in hospitals, especially a combination of stretcher and electric wheelchair, seems to be a concept that has attracted interest but using it as a walking aid with a carrying function has also been suggested. The development of such a device is cost intensive and includes expertise in many different areas such as: imaging technology, sensor technology, knowledge representation, information processing, fault recovery, hardware development, software development and motion planning. The programmes with emphasis on the health care field are research projects and products may evolve later but at present only pilot studies have been reported addressing the areas mentioned above. The psychological aspect of being dependent on a technical aid has been discussed but the impact of a mobile base with a degree of autonomy might change the perspective and make it necessary to reconsider the use of technical devices of this type in health care applications. As the elderly in particular are growing demographically the robots offer a great potential toward meeting the new demands if the flexibility is sufficient but the aspect of human attendance should not be neglected.

Therapeutical aids are also envisioned, either as an active movement of the patients limbs or as a passive device to be used in rehabilitation of disabled. The active therapy makes it necessary to synchronize two or more arms and this research area is important also when discussing manipulators as many tasks call for two arms to be completed efficiently. Another area developing is the creation of artificial organs but presently it is difficult to estimate the progress made until now.

Major clinical evaluations have not been reported until now but considering the level of development, especially for manipulators, there should be an increase in publications in this field. Even if potential users are working in close cooperation with technicians during the development phase the question still remains whether robots are possible as technical aids in a large scale. Comparison between different evaluations would be easier if standardization was adopted and a set of objective goals were given.

4. Status of Known Major Projects

A survey of literature and articles covering the development of robotics for rehabilitation purposes and the health care field should be combined with field studies. In spite of this some programmes that are considered as representative are described in this section and an attempt has been made to describe them both geographically and with respect to the duration in fig. 4.1.

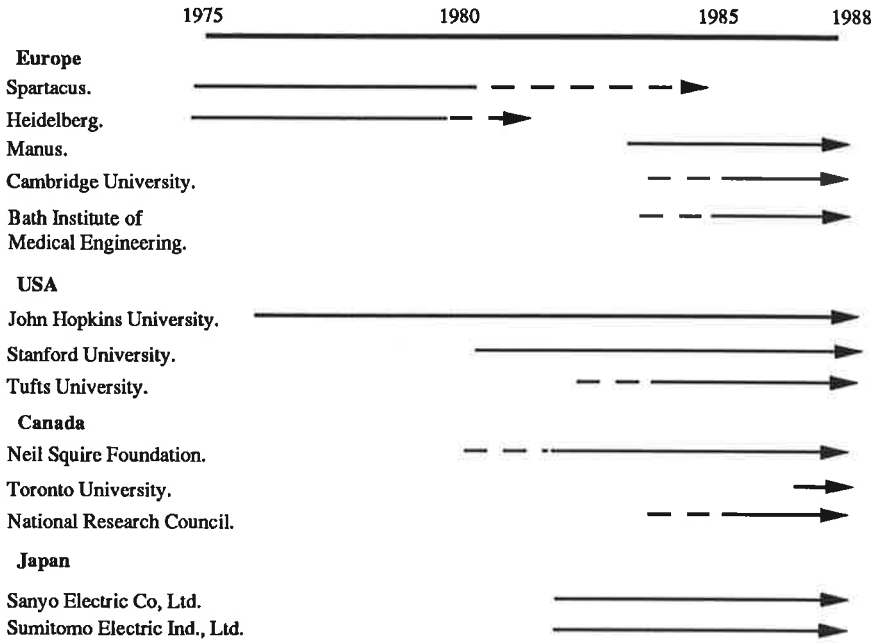

Figure 4.1 Known major projects and their duration

4.1 The Spartacus Project, France

This pilot study concerning manipulation of objects with a robot started in 1975 and the duration was limited to about five years. In 1981 the result was the "MAT-1 telethesis", an experimental telemanipulator to be used by quadriplegic users. After the official end of the programme clinical evaluations have been reported in 1983 and in 1985 (Kwee, 1986). The progress of development is supposed to have continued with the Master programme in France.

The aim was development of a prototype telemanipulator controllable by quadriplegics. An arm construction with six degrees of freedom was commercially available and control of the arm depended on a minicomputer. The system was to be designed with emphasis on retrieving objects from the floor and from shelves, and to allow manipulation of objects on a table. Additionally the man-machine interface was to be analysed thoroughly and work on reflexes was done in order to facilitate manipulation tasks. Essentially, the reflexes are preprogrammed support routines to control movements of the arm in its interaction with the physical environment (Guittet et al., 1979). Difficulties encountered in this early project included the state of computer technology, the level of development of the man-machine interface and safety aspects. Development of the system was depending on cooperation with potential users and the dialogue between technicians and the disabled is considered as very important. It seems as if most problems encountered today evaluating reports from later programmes were addressed already in this early project. Generally, the difficulties are based on the complexity in controlling the arm and gripper, and the expectations of a structured environment to accomplish the tasks in.

4.2 The Heidelberg Project, Germany

Another early project in Germany addressing the need of a manipulator to be used for rehabilitation purposes was concurrent with the Spartacus project. The results of the the project were reported in 1980 (Roesler, 1980). Presently there seem to be no further papers on work in the area of manipulators to be used in rehabilitation in Germany.

The manipulator developed in this project was similar to the one in the Spartacus project in integrating the electronics in the base supporting the arm but different control configurations were implemented and the manipulator specifications also differed (Guittet et al., 1979).

4.3 The Manus Project, The Netherlands

Officially this programme began in 1984 but it is lead by a member of the Spartacus project and concepts from the earlier work are included in the new approach of development of a wheelchair-mounted manipulator with computer assisted control structure. The mobility imposed by the wheelchair was considered in the Spartacus project but was probably ruled out because of the state of development both in mechanical design of the arm and the computer power available. In the Manus project, three prototype units are under construction and further development towards a product model is planned.

The components of the system have been custom made for the rehabilitation field and have been developed in two steps. A first specification phase followed by a second redesign and construction phase. This has led to an integrated product consisting of: a mechanical arm construction, electronics and computer hardware, software design and an interface to control the arm. As the intention is to use the manipulator in an unstructured environment emphasis is placed on interactive procedures in which the user directly controls gripper movements and wheelchair displacements. In addition preprogrammed routines are to facilitate certain tasks that require movements of higher complexity (Kwee et al., 1987; Kwee et al., 1988a; Kwee et al., 1988b). Work is proceeding in close cooperation with presumptive users and safety aspects have been of major concern during the course of the programme (Kwee, 1986). The device is interesting because it is an approach to solve the problem of mobility without extensive use of sensors. The user is supervising tasks all the time and has a clear view and thus control of the situation.

4.4 University of Cambridge, United Kingdom

This project started around 1984 and is aiming at the use of robots to assist in the developmental education of severely physically disabled children. Instead of restoring lost functions to a disabled user the system is intended to make it possible to explore and experiment in an unknown environment. The tasks the children will work with are supposed to be highly structured although the environment they are to be carried out in may be relatively unstructured. This results in primarily preprogrammed motions to be used with the system and a need of getting information about the environment. The project is in the developmental stage but early clinical tests have already been done (Harwin et al., 1986).

The robot used is an industrial robot with a moderate price and acceptable performance. A vision system has been added as have gripper sensors in order to allow for use in a relatively unstructured environment and to guarantee the safety for users. The vision system is based on a VME bus and will be custom made for the application. Coded markers will make it feasible to identify the objects to be used in manipulation tasks and thus an information processing system also has to be incorporated. Since the end effector is central to performance a custom made gripper is to be developed later in the project (Harwin et al. 1988). Development of a rehabilitation specific robot programming language is also in progress to make it easier to take advantage of sensor information and information in a data base (Gosine et al., 1988). Another aspect is to make programming feasible to teachers and therapists who have little knowledge of computer programming. This is in line with task oriented languages that are also being envisioned in industrial applications (Lozano-Perez, 1983; Volz, 1988).

4.5 Bath Institute of Medical Engineering, United Kingdom

This programme is supposed to have started around 1984 and is an example of the implementation of a manipulator in a work station concept. At an early stage a survey was made of potential users to determine the disabilities concerned and potential tasks that might be performed (Clay et al., 1985).

The system under current development is to be delivered on a trolley. An educational manipulator will be mounted on the table top and control will be achieved with a micro computer. In addition there will be a tape recorder, books and magazines which may be transferred to a book rest for turning of the pages and a telephone. This is a simple, relatively low cost approach but can be seen as a useful introduction to robotics and stresses the importance of working in close relationship with users and rehabilitation experts (Hillman and Orpwood, 1988). A structured environment is necessary when performing tasks with a system like this as the integration of sensors will make the equipment considerably more expensive. It is necessary to develop systems like this though, in order to conduct clinical evaluations and thus making it possible to improve the design after feedback from potential users.

4.6 John Hopkins University, U.S.A

Since 1976 an effort to develop an assistive device for the high spinal cord injured person has been made in cooperation with VA Medical Centers. It is a stationary work station with mainly preprogrammed routines that has been conceived and it is supposed to be used in a structured environment (Seamone and Schmeisser, 1986). Clinical testing has been conducted since the start of the programme and has contributed much to the overall system design. The device has been selected by the VA for transition to a manufacturing prototype model and it is expected that a small number of units will be placed in VA Medical Centers for evaluation.

The robot arm being used has been developed at the Applied Physics Laboratory at the University and is custom made for use with disabled. It is controlled by a low cost micro computer and has been designed to be used with a mechanical interface, a chin motion sensor. The tasks that can be accomplished include personal care and manipulation within an envelope that can be extended by travel on a horizontal track. Recently, an interface made within the parallel project at Stanford University has been incorporated in the work station (Lees et al., 1988a). The voice-controlled and prompted display system is hoped to greatly improve the ease-of-use of the JHU/APL robot.

4.7 Stanford University, U.S.A.

The Veterans Administration (VA) research programme at Palo Alto in rehabilitation robotics has been running since 1980 in collaboration with the University of Stanford. Two different concepts have been supported, a work station to be used primarily in vocational settings thus enabling disabled to get employment opportunities and a mobile robot to be used in a more unstructured environment. Development has been based on industrial robotics technology combined with research efforts within the project. The significance of voice-control has been stressed and research into a natural language interface is to begin (Leifer et al., 1988; Michalowski et al., 1987). The sophisticated user interface is the result of combining commercially available products and especially the great strides of voice recognition technology has made it possible to ensure safety for the operator. Presently, even the least expensive products to be used with micro computers achieve recognition accuracies of 98 percent when tuned correctly (Rosch, 1987). The desktop system is being developed to allow field trials as a vocational work station and the mobile device is being prepared to be used in clinical trials at the VA Spinal Cord Injury Center (van der Loos et al., 1988a).

The work station consists of an industrial robot to be controlled with a personal computer. The system is operated by voice commands and response to the user is given both by voice prompting and a graphic screen. Additionally a worktable has been designed with the robot mounted near the center of the table top surrounded by a refrigerator, a micro wave oven and an equipment holder. The end effector is a human hand prosthesis specifically designed for high performance manipulation tasks. Safety aspects and adaptability to different users have been incorporated in the system. The user interface has been designed to make control of the robot arm as easy as possible through a vocabulary that is intuitive and safety implementations include moves at low speeds, verification of commands and prevention of initiating conflicting tasks (Lees et al., 1988b; Lees et al., 1988c). The mobile robot is supposed to use the same arm but it will be mounted on an omnidirectional three wheeled vehicle to be controlled by remote control. Integration of sensor systems is thus necessary and much emphasis is put on the user interface that will rely on imaging technology, a natural language interface and graphic screens (van der Loos et al., 1988b). If communication is to be achieved with a natural language interface it could be in the form of a dialogue based user model as the area of natural language processing still is in i a research phase (Weischedel, 1986). Clinical evaluations have been performed throughout the course of the project and have influenced the design considerably (van der Loos et al., 1988a; Hammel et al., 1988; Hall et al., 1987). The results of the anticipated field trials for the stationary work station should be interesting and the mobile robot will probably be the first to be ready for clinical studies considering the present state of development in other projects.

4.8 Tufts University

Initially the project, begun in 1984, targeted commercially available, low cost robot arms for placement and long term evaluation in vocational environments. Three of the primary guidelines were flexibility, simplicity and affordability. The users were primarily non vocal students with multiple disabilities and were only capable of using a single switch interface to the computer used for control. As the pilot project was considered not to address the needs of the target population an effort was instead made to develop a more flexible programming environment for development specifically designed for rehabilitation purposes (Gilbert and Foulds, 1987). The programming language designed to accomplish this, Calvin, has been designed for rehabilitative robotics and is primarily making program development faster as sensor capabilities are not used extensively (Gilbert et al., 1987).

Presently three major clinical applications are supported: a general applications package, preparations to use a telephone switchboard and a set up to support industrial quality control. The common factor for these tasks is a reasonably to highly structured environment and easily defined repeatability of the tasks. The analysis of possible tasks to be performed has been conducted with reference to industrial robotics where application planning and decisions about how well tasks are to be achieved have been done since the introduction of robotics. The reason for investigating this area within rehabilitation is the users anticipated need for social interaction and the need to find an appropriate compromise between direct and automatic control of the arm (Demasco et al., 1987). The programming language designed is an interpreter with different levels implemented from position control of the robot to task level programming facilities, depending on the complexity of the predefined functions to be accomplished. As certain aspects of the program need to be easily adjusted in a clinical situation a compiled language makes users frustrated when changes take too much time.

4.9 The Neil Squire Foundation, Canada

This programme started in 1983 and has the purpose of providing the disabled population with an affordable aid to be used for manipulation by disabled. The foundation has delivered specially designed micro processor based technical aids to severely physically disabled earlier and thus have much experience from computer interfaces. The knowledge of robots was gathered through studies of medical robotics that were conducted during a survey including data collection through interviews with different groups, such as rehabilitation professionals, insurance claim groups and extended care workers. Many severely disabled were of course also interviewed. A preliminary test of the stationary work station developed has been conducted and clinical evaluation is planned within short (Fengler and Cameron, 1988).

The robot arm to be used in the work station has been developed for rehabilitation purposes and as it is also appropriate for manipulation in hazardous environments it has been adopted in a project concerning sub-atomic particle research. The arm has been mounted on a horizontal bar which allows travel sideways to enlarge the work area in a stationary work station. Achieving mobility with a wheelchair was considered but ruled out because the environment would be fairly unstructured and thus make preprogramming difficult. The desire is to develop a robot that is easy to use with preprogrammed tasks but which can also be used in an unstructured environment with the user moving the arm by direct commands. There is a conflict in this combination between the acceptable time for a task to be completed in and the users need of physical input capabilities. The user input control can be by either voice control, code, scan select, or the computer keyboard but the suitable combination has to be provided for every user as a special solution (Cameron, 1986).

4.10 University of Toronto, Canada

The work on robots to be used by disabled probably started in 1987 and is investigating the possibilities for a manipulator. The direct control strategy is preferred in accomplishing movements but the need for automatic support routines is stressed. The project is primarily aiming at a feasibility study of providing physically disabled with a robotic aid (Valettas and Goldenberg, 1988).

At present an automatic grasping capability and a custom made gripper with sensors are being developed. A low cost industrial robot is being used and control is through a personal computer with voice control facilities. The status of the system seems to be in a laboratory phase.

4.11 National Research Council, Canada

Work on the first phase of a larger project aiming at a mobile vehicle to be used in a relatively unstructured environment has begun in Canada. It is an initiative to develop a general automated guided vehicle that could serve as a starting point for many applications in the health care sector. The main purpose for development can be deviated from a reduction in costs and the potential patient independence that can be offered. Thus a high degree of flexibility must be achieved for the vast array of applications.

A commercially available platform is being used as vehicle and the first goal of the programme is to equip it with sensor systems both for obstacle avoidance and for human sensing. The components of the vehicle are being constructed as modules and the control system is being built with the same approach using a VME bus. The need for computer power will be accomplished with distributed processors. Modelling of the environment will be achieved with a combination of different concepts such as imaging technology, tactile sensing and ultra sonic transducers. The operating system and software to be used have been developed specifically for robot control and will be adapted to the current application (Korba et al., 1988).

4.12 Sanyo Electric Co., Ltd., Japan

Starting in 1983 this programme is aiming at the construction of a personal type of transfer supporting system for the handicapped. The system should be able to lift and move bedridden people, position them in wheelchairs and move them in such areas as the bath and toilet. The second trial model is to be completed in 1989 and a clinical evaluation will be carried out after construction of a prototype.

The mobile base has been constructed as a vehicle with two drive and two slave wheels, and the height adjustment is accomplished with two X-links supporting a back rest, the seat and the head rest. These rests are plates with belts arranged to make a transfer operation without the patients clothes or the bed clothes to be caught. The hardware to control movements is built around several micro processors to allow further development and modification of the system. The software implements many safety features and makes it possible for an inexperienced user to control the device in a simple way (Kume et al., 1988).

4.13 Sumitomo Electrical Industries, Ltd., Japan

This project has been concurrent with the programme at Sanyo mentioned above and has instead put emphasis on a patient care robot of a high performance type. The primary design criteria has been the development of a lifting arm to transfer patients from the bed to a transfer vehicle in a safe way. The main difference between the projects is the use of sensor information with this product and movements are to be almost automatic during the transfer operation from the bed. A second stage prototype is expected to be completed soon and evaluation will follow.

The mechanical parts resemble the ones used in the project aiming at the personal type of transfer supporting system. The mobile base though is of another type that allows omnidirectional movements and the horizontal plates inserted under the patient are equipped with custom made sensors to make an automatic transfer possible. The control system thus uses micro computers, opto-electric proximity sensors and two dimensional tactile sensors. The division of control into hierarchical blocks makes it easier to find physical space for the units, simplifies programming and reduces the amount of wiring required. Instead the data transmission lines have to be sophisticated and the system has been designed with one cable between the different control modules and the transmission speed is very high. The power consumption of the entire control system is approximately 15 W, in spite of the complexity, as the device is to be driven by battery power for long periods of time. Although this system approaches the automated system that can be expected in the future supervision is still necessary as the steps of detecting the bed height, inserting the plates beneath the patient and actually lift the patient has only been tested with a healthy person able to take precautions if anything goes wrong (Yamada et al., 1988).

5. Special Projects

Several other projects can be found in literature but as they are either unique within the area of development or are aiming at a specific product to be completed for an individual the references are given in this section instead.

A project at the California State University is addressing the needs of disabled children born with their handicap. The robot arm is used as an educational system to facilitate learning and the project is thought to be aiming primarily towards therapy (Cook et al., 1988).

At Santa Clara University a device for active therapy of joints is being modelled. The main problem discussed is how to synchronise two arms working simultaneously (Khalili and Zomlefer, 1988).

A passive therapy aid to be used for reach and touch exercises, with objects held at a variety of points in space, is being developed at the Metropolitan Center for High Technology (Kristy, 1988).

A private initiative to provide a wheelchair-mounted robot for manipulation has been reported. Although the system seems simple it appears to be very useful and discussions concerning social and health authorities are held regarding financial support of technical aids (Zeelenberg, 1986).

A work station designed for a vocational setting at Boeing Computer Services included two arms as the work area covered by one arm was not considered as enough. The voice operated system was fully functional in 1986 and the operator was able to work independent of supportive aid from coworkers (Fu, 1986).

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