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Rehabilitation robotics from past to present - a historical perspective

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Abstract

This paper attempts to look critically at the development of the use of robotics in rehabilitation since the early 1960's until the current day. Not only the successes but also the apparent failures will be considered. It is important that those working in this field today are aware of their heritage. By looking at the historical perspective, it is hoped to provide pointers for the way forward in this challenging and rewarding field of engineering.

1. Introduction

Most reviews of work in the field of Rehabilitation Robotics cite work going back to the early 1960's. Since then many projects have taken place. Some have come and gone with few obvious positive results, some have been an ongoing development process, while a few have resulted in marketable products which are widely benefiting disabled people. All have, however, contributed to the volume of knowledge from which those now working in this field of research benefit. It is important not to forget the lessons of the past. This paper aims to refresh our memory of what has gone before. In some cases the problems which have defeated earlier researchers may now be overcome by the application of current technology and understanding.

The area of discussion could be huge so it is necessary to provide a definition of terms:

- Robot: "A re-programmable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.". Although this definition was intended for industrial robots, it identifies the key features of programmability, flexibility and movement.
- Rehabilitation: "the restoration of a person to an optimal level of physical, mental, and social function and well being."

One of the aims of this paper is to emphasise the wide variety of devices and projects which come under the heading of rehabilitation robotics. In order to illustrate this variety, the projects selected are those which were the first of their type, those which have had a large number of users and those which are now, or have been, commercially available.

2. Early Work

The first referenced rehabilitation manipulator was the CASE manipulator [1], built in the early 1960's. This was a powered orthosis with four degrees of freedom, which could move the user's paralysed arm. Another early powered orthosis was the Rancho Los Amigos manipulator [1] with seven degrees of freedom.

Work in the more specific area of rehabilitation robotics started in the mid 1970's. One of the earliest projects was the workstation based system designed by Roesler [2] in Heidelberg, West Germany. The purpose designed, five degree of freedom manipulator was placed in a specially adapted desktop environment, using rotating shelf units.

Another early workstation system was that of Seamone and Schmeisser at the Johns Hopkins University, supported by the Veterans Administration in the United States from 1974 [3]. The arm of this system was based around an electrically powered prosthetic arm, mounted on a horizontal track. Various items of equipment (e.g. telephone, book rest, computer discs) were laid out on the simple but cleverly designed workstation table and could be manipulated by the arm using preprogrammed commands.

In France the Spartacus robot [4] was based around a large high quality manipulator from the nuclear industry. With such a potentially powerful device, safety had to carefully considered and early training of users was done with the arm behind a clear screen. This project has led to the Manus project in Holland and the Master project in France, described below.

Another early project in the United States (1970's) was the work of Mason [5] at the Veterans Administration Prosthetics Center in New York. This was the first use of a robot arm mounted to a wheelchair, potentially offering much greater freedom than a workstation mounted system. The four degree of freedom arm was beautifully engineered, and its novel telescoping design allowed it to reach to the floor or the ceiling.

3. Assistive robots

3.1 Fixed site robots

One of the most prominent research centres since the early 1980's is that led by Leifer at Stanford University, California, and Van der Loos at the Palo Alto VA Hospital. Their early work led to the development of several generations of the DeVAR (Desktop Vocational Assistive Robot) workstation using a Puma 260 industrial robot. The DeVAR IV workstation [6] was aimed at a vocational environment, with the Puma arm mounted upside-down on an overhead track, thus increasing its working envelope.

The Unimation Puma is a high specification industrial robot. One robot which has been widely used in rehabilitation robotics and has been actively promoted by the manufacturers as being suitable for rehabilitation applications is the RT series produced by OxIM (Oxford, UK). An early system based around the RTX robot was developed at Boeing in Seattle initially for one of their own disabled programmers [7].

In France the Master project [8], a continuation of the Spartacus work, used an RTX robot in a workstation environment. The manipulator was mounted at the back of the workstation, with shelving units on both sides which may be accessed by the arm. More recently, as part of the European TIDE funded RAID project [9], an RT200 robot was built into an extended workstation. At the end of the RAID project the workstation was commercialised by the manufacturers of the RT robots as well as a similar system by Afma robots in France.

Normally the most efficient and cheapest way to produce a robotic system is to use a commercially available device. There may however be good reasons for designing a manipulator for a specific situation. Valid reasons include more successful integration of the overall system, designing to a known specification for more effective operation, a possibly cheaper system if the specification is simple and finally avoiding reliance on a particular device supplier. At the Neil Squire Foundation in Vancouver, Canada [10], the Regenesis workstation robot was developed, based around a six degree of freedom manipulator mounted on a horizontal bar, thus allowing sideways movement over a bed or table. This system was made commercially available.

3.2 Powered Feeding devices.

Although robots are defined above to be multifunctional, a device which is programmable for a specific task can also come within our definition. The feeding application is one area where robotic devices have been used to assist in the feeding function.

In 1987, as a Masters Research project at Keele University, Mike Topping set himself the task of helping his neighbour Peter, a 12 year old boy with spastic paraplegia, to feed himself. Initially he used a Cyber Robotics educational robot. From these beginnings came the Rehab Robotics company which has sold more rehabilitation robots than any other with their Handy 1 robot [11]. Subsequently the functionality has been increased to include applying make up, shaving and painting.

It is this area of feeding that the boundary of what is and is not a robot has become blurred. Other powered feeding devices include the Winsford Feeder (US) which has been on the market for 15 years, the Neater Eater (UK), and the MySpoon (Japan).

3.3 Mobile assistive robots

Although the use of robotics is intended to bring flexibility, the workstation approach is itself limited. A fixed site robot arm can only interact with objects arranged (by an able bodied person) around it. However in daily living the objects to be manipulated may include a book on a book shelf, preparing a meal in the kitchen and operating a word processor in the study. The idea of a mobile robot is therefore very attractive. Two approaches may be considered, an autonomous mobile robot freely roaming about the house or a manipulator mounted to an electric wheelchair which moves with the user.

The Manus wheelchair mounted manipulator is one of the successes of rehabilitation robotics and has been sold commercially by Exact Dynamics since 1990. It was developed at the Hoensbroek Institute for Rehabilitation Research and TNO in Delft in the Netherlands from 1985. The work was led by Kwee [12], who previously worked on the Spartacus project.

Another interesting approach to the design of a wheelchair mounted manipulator was developed by Jim Hennequin and his Inventaid company. This manipulator was based around a novel pneumatic actuator, known as an "Air Muscle". Simplicity (with implications for low cost, reliability and easy maintenance) was one of the aims of the project and the basic system involves no digital or microprocessor circuitry.

The other wheelchair mounted robot which is currently commercially available is the Raptor arm, from the Rehabilitation Technologies Division of Applied Resources Corporation (RTD-ARC, New Jersey, US) [13]. The Raptor is much simpler that Manus, having 4 degrees of freedom and gripping and a less sophisticated user interface system. While having less functionality than Manus it is also significantly cheaper.

While a wheelchair mounted robot can be envisaged as a “third arm”, if a manipulator is mounted in a powered mobile base it is more rightly seen as a robot servant. Its role is to “fetch and carry”.

One of the earliest projects attempting to use a mobile robot in a rehabilitation setting was the MoVAR (Mobile Vocational Assistive Robot) project at Stanford University [14]. A small Puma industrial arm, equipped with a video camera to allow operation in another room, was mounted on an omnidirectional mobile platform.

Engelberger [15] describes rehabilitation applications of the HelpMate robot, now being sold by the Pyxis Corporation (San Diego, US). Although aimed primarily at a hospital environment to bring food trays etc. to a patient in bed, the application as a fetch and carry robot for the disabled is obvious. However in spite of several projects in this area very little progress has been made towards realising a useful mobile rehabilitation robot.

4. Mobility

The assistive robots mentioned above all use, to some degree or other, the manipulative ability of a robot. However we do not want to limit our definition of the term “robot” to purely manipulative devices. Within mainstream robotics a major area of both research and commercial application is that of “Automatic Guided Vehicles” (AGV). Within the rehabilitation field this research has led to a number of “smart” wheelchairs incorporating features such as obstacle avoidance, tracking along a wall, track or manoeuvring through a door.

One approach is to adapt a standard commercial base. For example the CALL Centre in Edinburgh, UK have many years experience in this area. In their initial work [16] they used a standard electric wheelchair to produce a smart wheelchair for children and teenagers. In their latest smart wheelchair the Smart Controller acts as if it was a second joystick plugged into the DX (Dynamic, New Zealand) wheelchair bus system. Various Smart Wheelchair ‘tools’ can be easily selected in different combinations to suit the pilot and environment.

The alternative approach, as used by the CEC TIDE funded OMNI project [17], was to purpose build an omni-directional wheelchair integrated with autonomous control features.

Assistance with mobility does not necessarily mean that the powered robotic device transports the user. In the “Meldog” project a mobile robot was used to guide a person with visual impairment [18]. The robot was able to lead a blind person around a known environment using a scanned street map of the area in the robot's memory.

5. Orthotics and prosthetics

It is clear from the early work mentioned above that orthotics have been closely associated with rehabilitation robotics. More recently Rahman and colleagues at the AI duPont Institute (Wilmington, US) have designed the anti gravity arm orthosis [19]. While this is a balanced system, with no external power supply the Mulos project [20] is a powered upper limb orthotic system.

Although there is a lot of commercial work in prosthetic arms and hands very little of this has used robotic technology, but rather has been a development from existing technologies. However, one computer controlled upper arm prosthesis is the Utah artificial arm and hand developed by Jacobsen [21]. Kyberd’s work on the Southampton prosthetic hand development is also significant [22].

6. Therapeutic applications

A major area of work within the wider field of rehabilitation robotics, especially over recent years, has been the use of robotic devices to assist in therapeutic interventions. Much of this interest has been in rehabilitation following a stroke. Several projects have aimed to improve upper limb function following stroke. At Palo Alto the MIME system [23] can be used both in a passive or active mode or a bilateral mode in which the patient attempts to move both the affected and unaffected limbs. While MIME uses two Puma robot arms, the ARM Guide developed by Reinkensmeyer and colleagues uses a novel robotic device [24]. The MIT-Manus system [25] is similarly designed for stroke rehabilitation and is now available as a commercial product Another stroke rehabilitation project is the GENTLE/S project [26] which encourages the patient to move (against a resisted Haptic Master arm) in a computer generated virtual 3D room.

At Santa Clara University two planar robot arms have been used for the rehabilitation of joints following surgery [27]. The two arms, each with force sensors at base and gripper, hold firmly two adjacent limb segments (e.g. upper and lower leg). Using the two robots, the leg is manipulated, with the joint under compression for effective rehabilitation.

7. Robots in education and other applications

Several projects have been aimed specifically at disabled children in an educational context. For example, Cambridge University [28] used the RTX robot as an educational aid for children with cerebral palsy. For such children the ability to "play" is missing. Therefore the robot was used to simply drop a brick onto a drum, producing an interesting noise. This then progressed to colour matching exercises and at a more advanced level to enable the children to take part in cookery and chemistry lessons.

A completely different area of rehabilitation in which robotics is being applied is in communication for people who are deaf and blind. The Dexter finger spelling was deigned by Jaffe [29]. It approaches the problem that while deaf-blind people are extremely competent at finger spelling as a means of communication, most other people are not. Dexter therefore translates from text to finger spelling. In appearance it is configured like a human hand.

Conclusions

Ultimately this work will only benefit people with disabilities if it is made available to them. This will nearly always be on a commercial basis. Therefore the success is measured in the commercial availability of devices.

Two products stand above others, at present, in terms of commercial success. More than 250 Handy 1’s have been sold by Rehab Robotics and Exact Dynamics have sold more than 150 Manus robots and financing the purchase of Manus by end users has been under discussion with the Dutch Government. For sales of assistive robots to significantly increase, the issue of cost will need to be addressed. It will be interesting to see how the Raptor’s compromise of lower functionality at a lower cost works out.

It is probable that in the near future we will see increasing sales of robot mediated therapy systems, where price may not be such an issue.

The other area in which the use of robotics in rehabilitation is likely to grow is in novel application areas where the robot is not so obviously a traditional "manipulator arm".

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