Invited Norbert Wiener lecture:

THE MOON OVER DUBROVNIK - A TALE OF WORLDWIDE IMPACT ON PERSONS WITH DISABILITIES

James B. Reswick

Ladies and Gentlemen! It is truly a great honor to stand before you today as the second Norbert Wiener lecturer. It was 28 years ago that I, young and untraveled, was invited along with only two other Americans to come to a place, unknown to me, somewhere in a country that most of my countrymen thought was hidden behind an iron curtain. Of the other two invitees, one was Norbert Wiener who knew, as I did not, that he and his wife would find Opatija to be a beautiful resort fashioned many years ago by the Hapsburgs for their own pleasure; a place on the Adriatic Sea where the finer things of life and of relationships could be made manifest. It was a profound experience for me, one of those rare events that truly change the direction of one's life. That seminar spawned a series of triennial meetings of which this is the tenth. It is remarkable to me how, through the years, these meetings have been singularly focused on the major advances on technology applications for people with disabilities. A study of the collection of proceedings from each of the meetings constitutes an historical survey of most of the significant events. With few exceptions, all meetings have been here in Dubrovnik and it has been my good fortune to have attended every one.

What can be said after nearly 3 decades of effort in our field and of its impact? I propose to attempt only a partial answer by following the "red thread of development" of one technology that has been present from the beginning. The robotic manipulator is my choice since, among other reasons, it was my own research in this field that brought me to the first symposium. At that time, we called our device an "arm aid" as it was anthropomorphically designed to fit around a human arm, but it differed in no way from the present day "robotic arm". Other names include, "externally powered orthosis", "orthotic arm", "interactive robotic aid", "robot-manipulator", "augmentative manipulator", "rehabilitation robot", "manipulation aid" and the like. I make no distinction between the manipulator that is anthropomorphically formed around an impaired human arm and one that operates some distance from a person. Not included are the close relatives (even twins) in the field of externally powered prostheses--there are simply too many. Also, my comments are restricted to units that have been actually built and evaluated to some extent on or by a human being; thus a number of important theoretical issues that have been reported on will be bypassed. It turns out that, with only a few exceptions to be included near the end of these remarks, virtually every significant development in the field has been reported in the series of proceedings of these international symposia. But before we begin this tour through the past, let me quote from the introductory remarks that were made by Professor Rajko Tomović 28 years ago at the first symposium in 1962. In talking about the automatic control of human extremities, he said, "Let us therefore observe specific features of human extremities control:

- *Human extremities represent a very complex kinematic system while engineering actuators have relatively few degrees of freedom (linear and/or rotational movements).*
- *The many degrees of freedom on our extremities require control signal sources of high information content. This fact is important and we shall concentrate mainly on this problem in our further discussion.*
- *The control signals used are of two distinct origins: one set consists of conscious control signals, whereas the second governs the reflex loops. These signals are of sensory origin."[1]*

How prophetic Dr. Tomović was will become apparent before I finish.

THE RANCHO GOLDEN ARM

It was not until the 1969 symposium that manipulator hardware was first reported. In two papers A. Karchak, J. R. Allen, and V. L. Nickel presented their early developments on CO_2 powered arm manipulators that were used successfully on a number of polio patients at the Rancho Los Amigos Hospital in Downey, California [2,3]. The final product of their developments was the "Rancho Golden Arm" which was an electrically controlled arm orthosis with 6 degrees of freedom. Each degree of freedom (the seventh was finger pinch) was controlled independently by one of seven tongue operated microswitches. The Golden Arm (aluminum parts were anodized to a gold color) is particularly noteworthy in this discussion because a number of paralyzed persons were fitted and used the system for activities of daily living for years. I personally knew a lady, paralyzed by polio, who used her electric arm in her home with great skill for more than five years. At this point I wish to make two very important observations.

1. No other maniplator or powered orthosis has ever come close to being used outside of the laboratory or clinic as much as has the Rancho Golden Arm.
2. Every person with whom success was achieved at Rancho Los Amigos Hospital had intact sensation (polio or M.S.).

THE CASE RESEARCH ARM AID

It was at the same meeting in 1969 that Howard Apple and I presented our work with the Case Research Arm Aid [4]. The first version of this consisted of a very high performance numerically-controlled gas-operated orthosis that could be operated from a tape recorder with stored programs for various tasks. The second version used the same manipulator but the control system was driven from 3 pairs of EMG sites that related to the three axes of an orthogonal coordinate system. A unique computer program solved the problem of controlling 4 angular degrees of freedom of the manipulator with 3 input signals. The Case Research Arm Aid was designed, as its name implies, to be only a research tool. The first version of the Case Research Arm Aid was operated by one quadriplegic person in the clinic and the second version was demonstrated by one graduate student; it was never regularly used by a person for activities of daily living.

HEAD CONTROLLED ORTHOTIC BRACE

The next manipulator development was reported at the 1972 seminar by A. G. Potter and J. H. Friedman [5]. At the Iowa State University, Ames, Iowa and the Methodist Hospital, Des Moines, Iowa, they added electric motors to a wheelchair-mounted Engin feeder. Their main interest was in a head actuated device that provided input signals for "end point control". This system was evaluated only by a "normal" subject.

SYNERGETIC CONTROL OF A REHABILITATION MANIPULATOR

At the 1972 meeting M. R. Marić and M. M. Gavrilović studied the problem of coordinate transformation for control of a research manipulator [6]. The system was not reported to have been evaluated on a person with paralysis.

OCULAR CONTROL OF THE RANCHO ELECTRIC ARM

At the same meeting in 1972, M. L. Moe and J. T Schwartz reported on a control system using infra red reflection from the eye balls to provide input signals to a computer that drove a Rancho Electric Arm [7]. The system was evaluated on one patient with paralysis.

WARSAW EXTREMITY-LIKE MANIPULATOR

In 1975 a. Morecki and K. Kedzior presented a pneumatic- powered body-mounted orthotic arm aid developed at the Technical University of Warsaw and Warsaw Academy of Physical Education [8]. It was reported to be controlled by EMG signals. A prototype was evaluated on "patients" but it was apparently never produced for clinical use.

ROBOTIC AIDS FOR THE SEVERELY DISABLED

It was at the 1978 symposium that L. Leifer, B. Roth, D. Keller, J. Sachs and I. Perkash reported on the first of a series of manipulator systems that have occupied

Professor Leifer and his colleagues up to the present time [9]. This work began at Stanford University, Palo Alto, California but moved later to the nearby Veterans Administration Hospital. This paper was called a "feasibility assessment" by the authors and employed a commercial Unimation 250 electro-mechanical arm. Since then Professor Leifer's robotic arms have become ever more sophisticated with versions mounted on mobile units and others responding to voice control. While many persons with paralyzed extremities have been trained to use these machines in the laboratory/clinic environment, none have been reduced to commercial form for general use.

A SIMPLE LOW COST MICROPROCESSOR CONTROLLED MEDICAL MANIPULATOR

At the 1981 symposium, B. L. Davies and E. C. Semple described an undergraduate project undertaken at the University of Adelaide, South Australia [10]. This was a table-mounted 3-axis manipulator that was evaluated for use by children. Subroutines and movement elements were programed on E-proms to be called for by simple switch movements. Various eating and drawing motions were available. The report described the use by one child over a period of some weeks. No other units were apparently built.

ACTIVE ARM ORTHOSIS AND EXPERIENCE WITH ITS PRACTICAL USE

In 1984 D. Hristrić, M. Vukobratović and M. Timotijević, of the Mihailo Pupin Institute, Beograd, Yugoslavia, reported on a wheelchair mounted three-axis manipulator controlled with a three axis joy-stick intended for a user with one non-functional arm [11]. The device was reported to have been used successfully by a person in her home. A second unit was reported to have been sent to the Texas Rehabilitation Institute for evaluation.

This "manipulator tour" is not intended to be a complete survey of all worldwide developments. I have probably omitted many significant efforts. However, there are some others that have not been reported on at Dubrovnik that I would like to mention. They are competently reported on in the Monograph 37 of the World Rehabilitation Fund entitled "Interactive Robotic Aids--One Option for Independent Living: An International Perspective edited by Richard Foulds [12].

SPARTACUS AND MANUS

The first and perhaps largest world effort reported in Monograph 37 are the Sparticus and Manus systems developed in France and the Netherlands and reported on by H. H. Kwee. The Sparticus project was a five-year project that was considered from the beginning to be a "feasibility study". In the beginning a commercial MA-23 nuclear telemanipulator was used. Later the Spartacus MAT-1 "telethesis" was developed. The Sparticus systems were used by a number of persons with disabilities but only in the clinical laboratory. At the time of the publication, the Manus project in Holland had only just begun. According to Dr. Kwee, it was intended to be a continuation of the Spartacus project.

NEIL SQUIRE FOUNDATION MANIPULATOR

One of the very few "commercially available" manipulators intended for persons with disabilities is the system reported on by W. Cameron in Monograph 37. Mr. Cameron is associated with the Neil Squire Foundation, Vancouver, Canada. I understand that his manipulator is available for around $5000 but that only a very few, if any, are being used by disabled persons at the present time.

APL/JHU ROBOT ARM WORK STATION

W. Seamone and G. Schmeisner of the Johns Hopkins Applied Physics Laboratory near Baltimore, Maryland developed a robotic manipulator work station system with support from the U. S. Veterans Administration. They report on their work in Monograph 37. Two of the work stations were evaluated at VA Hospitals in Richmond, Virginia and at Hines, Illinois. While these evaluations suggested practical utility of the system, it has not been commercially developed.

AUTOMATIC FEEDING DEVICE

Finally, I would like to quote from a catalog of North Coast Medical, Inc., San Jose, California, one of the USA suppliers of equipment for rehabilitation:

> "Winsford Self-Feeder -- Only a slight move of the head operates the Winsford Self-Feeder. Can be controlled by either the chin strap or the remote hand-foot control. The automated spoon, dish and glass holder are operated by a 6 volt rechargeable battery. Adjust height as necessary. Carrying case included.
>
> NC38010 Price $1200.00"

As I have stated, the above list is not complete but it is long enough to present a valid picture of some 30 years of development of manipulators intended to facilitate the activities of persons whose arms are paralyzed. Now for the question. Why, after so many years and so much effort (I don't dare to estimate the money spent so far) is there only one manipulator, a very simple automatic feeder, listed for sale by any distributor of rehabilitation equipment in the world? A part of the answer has been suggested by A. Batavia and G. Hammer in a paper entitled "Consumer Criteria for Evaluating Assistive Devices: Implications for Technology Transfer" [13]. They used a modified three stage Delphi method to identify and prioritize criteria of consumer acceptance for some 11 types of assistive technologies. For "Robotic Arm" the following criteria are listed in order of priority:

1.Effectiveness	8.Durability
2.Operability	9.Physical Security
3.Dependability	10. Learnability
4.Affordability	11. Ease of Maintenance
5.Flexibility	12. Supplier Repair
6.Compatibility	13. Physical Comfort
7.Personal Acceptance	14. Consumer Repair
15. Ease of Assembly	

Thus "effectiveness" and "operability" are the two most important criteria for consumer acceptance. It appears that rehabilitation manipulators have not been successful because they are simply not effective and lack sufficient operability. So far, consumers have not accepted any manipulators (other than the Winsford Self-feeder) for long term use in their homes. Why have they not been found to be effective?

Professor Tomović stated the problem 28 years ago as I quoted at the beginning of this paper. He knew what had to be done, but I believe he, being the optimist he is, underestimated, as have so many others including myself, how difficult it would be to approach the effectiveness of a human arm and to imitate its human control (operation). I can only conclude from the experience at Rancho Los Amigos Hospital where, over 30 years ago, patients with intact sensation actually accepted manipulators with the most rudimentary control systems, that we have all grossly underestimated the role that proprioceptive feedback plays in the control of a human extremity. We have, to our detriment, concentrated on computer systems and input control signals when we should first have solved the feedback problem. The message to researchers in the field is clear.

And so, after three decades, we have become humble but not discouraged. We need only examine the many outcomes, some unexpected, that have accumulated through the years. I remember how the collaboration between Professor Lojze Vodovnik and myself began at the first symposium, how the then new field of FES grew in Ljubljana and in Cleveland to affect the lives of so many persons with disabilities, the professionals who serve them and the researchers who explored new frontiers of technology. I remember Barry Romich, one of my students who worked on the Case Research Arm Aid and how he went on to found the most successful company in America that provides rehabilitation technology at affordable prices to many thousands of persons with disabilities. These are just two of many, many outcomes in my own experience. You and the others who have come before you to these Dubrovnik meetings could relate similar stories.

So, while the impact of research on manipulators has yet to be achieved for persons with disabilities, I know it has to come. Meanwhile Luna or Selena, if you prefer, sends her warm rays down on us, as she always has, here in Dubrovnik. Her message is one of admiration for the men and women who dare to achieve what seems to be impossible. She beams her congratulations for our achievements, whether expected or not and she shines with her confidence that noble motives always assure positive outcomes.

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