Workstation Robotics: A Pilot Study of a Desktop Vocational Assistant Robot

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Rehabilitation robots are increasingly being viewed as an appropriate assistive technology interface for persons with disabilities. The Desktop Vocational Assistant Robot (DeVAR™) system is a voice-controlled robotic workstation designed to enable persons with severe mobility impairments to function independently in a work environment. This study examined the overall efficacy of the DeVAR™ system, the level of expertise required for therapists and support personnel, routine maintenance requirements, and the readiness of the device for a multicenter evaluation.

Two precommercial DeVAR™ workstations were installed at selected sites. The pilot study spanned 8 months in which staff members and four subjects with high-level quadriplegia evaluated the systems extensively. Responses were generally favorable regarding ease of use and overall training process. Subjects recommended modifications, including incorporation of a noise cancellation microphone, more effective use of workstation space, and addition of vocational tasks. All respondents thought that if the recommended changes were implemented, DeVAR™ would have potential as a vocational assistant.

The small number of subjects was due to the limited subject pool available for the study. On the basis of pilot results, the Veterans Administration Rehabilitation Research and Development Service, Baltimore, Maryland, is conducting a national multicenter evaluation to determine the overall utility and commercial readiness of the DeVAR™ system.

In the past, employment opportunities for persons with severe mobility impairments were extremely limited. However, today's electronic technologies have created a shift in the job market that is evidenced by the influx of information-processing professions. Coupled with the passage of the Americans With Disabilities Act of 1990 (Public Law 101-336), this movement toward a more information-intensive job market has laid the groundwork for employment of persons with disabilities. Additionally, recent advances in voice recognition computer interfaces and related technologies have enabled persons with severe mobility impairments to enter data and process information at performance levels rivaling those of computer users without disabilities.

Unfortunately, even with legislative assistance and improved computer access, persons with severe mobility impairments may be denied positions by employers who fear that they must hire part-time or full-time assistants to carry out support tasks requiring manipulation as well as self-care activities. Assistive technologies, such as robots, can provide the interface through which personal and attendant activities can be achieved independently, enabling persons with severe mobility impairments to become effective and productive members of the workforce.
Robotics technology appears to be in a developmental stage similar to that of business computers in the early 1960s (Awad & Engelhardt 1985). Industrial robots are constantly gaining advanced language and mobility; these gains lead to greater commercial application, such as in the manufacture of automobiles and semiconductors. The application of robotic devices has also pervaded the health and human services field and given rise to the area of rehabilitation robotics. By replacing or augmenting a person's manipulation skills, the robotic aid can decrease dependence on attendant care, improve self-esteem, promote mental stimulation, and allow greater mastery of the physical environment. Computer-based robotic manipulators can provide persons with severe mobility impairments with an interactive aid for performing personal and vocational activities. Additionally, spinal cord injury (SCI) research has shown that increased client involvement in purposeful activity enhances personal health and increases longevity (Heck, 1988; McCormack, 1988).

Rehabilitation robotics can be divided into two main categories: workstation (fixed-location) and mobile systems. This article focuses on a workstation-based manipulator intended for use by persons with severe mobility impairments in a vocational setting.

System Description

The Palo Alto Veterans Affairs Rehabilitation Research and Development (RR&D) Center, in collaboration with Stanford University's School of Engineering, developed the Desktop Vocational Assistant Robot (DeVAR™)1 system. The workstation is arranged in a predetermined fashion with all peripheral equipment positioned in specific locations so that the robot can find each item. The DeVAR™ workstation module measures 4 ft from front to back and is 8 ft wide; this size can be accommodated in most office settings. The system is designed to blend with existing office furniture.

1Manufactured by Independence Works, Inc., 831 Esplanada Way, Stanford, CA 94305.
DeVAR™ uses a VOTAN VTC 2100 voice recognition system\(^2\) that allows persons with severe physical impairments to control a robotic arm and manipulate objects within the workstation area. The manipulation capability is built around a PUMA™ 260 robot arm\(^3\) with a modified Otto-Bock Greifer prosthetic hand\(^4\) as the gripper. The robotic arm is suspended on a 4-ft overhead track above a 4-ft x 3-ft main work surface. This main work table is flanked by two side surfaces to form a U-shaped workstation for the user. The track also allows the robot to access the overhead shelving and side surfaces (see Figure 1).

A Compaq Desk Pro\(^5\) computer serves as the high-level robot controller (brain). A microphone, speaker, and phone line connect to the VOTAN board in the computer for voice input and output, allowing interactive communication between the user and DeVAR™. The color prompt monitor displays task commands and the current status of robot activity. An X-10 Powerhouse™ environmental control unit\(^6\) is also linked to the computer to give the user voice control of the lights, a Macintosh™ Classic computer, and a call help module. The Macintosh™ serves as the user's application computer (e.g., for word processing or data entry functions) and is separate from the robot controller to clearly delineate user and robot commands. As a backup control method, the operator can also use the Macintosh™ computer to send robot commands.

Because the robot maneuvers close to the operator's head, safety is of the utmost importance. For this reason, the following features are built into the system: operation at relatively slow speeds; a limited force level (5 lb); and the ability of the operator to stop the robot at any time by saying the word “Stop,” making any loud noise, or hitting an emergency stop switch by tilting his or her head approximately \(\frac{1}{2}\) in. to the right.

No prior computer knowledge is required for the user to operate the DeVAR™; the robot controller is preprogrammed to perform complex tasks in response to one-word or two-word commands. This preprogramming approach to operation was selected to save the user time and energy and to minimize operator training and high-tech intimidation. However, at any time, the operator can use directional commands (up, down, right, etc.) to pilot the robot; for example, to bring the telephone receiver to his or her left ear or to perform a nonprogrammed function. The tasks are divided into three categories: vocational support, activities of daily living, and environmental control. During the pilot study, DeVAR™ was programmed to manipulate and file computer printouts; select, load, and return floppy disks; select and dispense medication (throat lozenges); retrieve and return a mouthstick; retrieve and return a phone receiver; and scratch an itch on the user's face. For tasks that involve bringing an item, such as a spoon, to the user, the robotic arm stops at a predetermined end point 6 to 12 in. from the user's head; the user then pilots the utensil to his or her mouth using the directional commands. The standard set of tasks can be used as is or adapted to meet individual needs.

The successful completion of the DeVAR™ subject trials by the Palo Alto RR&D team provided impetus to proceed with the technology transfer process. The next step was to pursue a clinical evaluation of the system outside the development environment. Because of the sophisticated level of the workstation hardware and software, the Veterans Administration RR&D Service decided to conduct a pilot study. Results obtained from pilot testing would determine the overall efficacy of the system and whether or not DeVAR™ justified further refinement or evaluation.

**Objective**

The primary goals for the pilot evaluation were to verify the flexibility, operational and performance features, long-term reliability, and, above all, safety of the system. The study also examined DeVAR's™ utility in assisting people with high-level quadriplegia to attain independence in a vocational environment. This test of DeVAR's™ clinical efficacy included assessing the appropriateness of the current set of tasks and the need for additional tasks as identified by the subjects.

Other objectives were to determine the background and level of expertise required for the therapist and biomedical staff members as well as the degree of support routinely required to maintain DeVAR™ operation and resolve system failures. The study also examined the developer's instructional materials (manuals and videotapes) for installation, disassembly, staff members and subject training, and technical support. The final objective was to assess DeVAR's™ readiness for a national, multicenter evaluation.

**Method**

Two precommercial DeVAR™ systems were procured for evaluation. The first DeVAR™ system was placed at the Veterans Administration Technology Transfer Section, RR&D Service, Baltimore, Maryland, and the second was located at the Veterans Administration Medical Center, Houston, TX.
Spinal Cord Injury Service, Richmond, Virginia.

The placement of the first system at the site allowed the project monitor and biomedical engineering technician to become familiar with the operation, training techniques, and technical management of the unit. The second system was evaluated extensively by four men with SCI who were selected according to criteria established in the pilot protocol (see Table 1). Subjects A, B, and D had been previously employed as a computer programming instructor, a mail carrier, and a chemical officer in the U.S. Army, respectively. Subject C was employed at the time of the study as a computer programmer. All four subjects used the system in the identical workstation configuration. Only the emergency stop switch and Macintosh™ trackball and keyboard were custom positioned for each user.

Results

Subjects required from 3 to 5 hr to operate the system safely and independently. The DeVART™ performed all tasks reliably and efficiently. Three subjects recommended more efficient use of workstation space. Suggestions included the following:

- adding a motorized reference carousel
- replacing one of the copy stands with a book rack and page turner
- relocating the prompt monitor next to the Macintosh™ computer to minimize head and neck fatigue for the user.

The subjects' judgment of task usefulness are shown in Table 2. For the most part, all subjects thought that the preprogrammed tasks were essential, useful, or both. Subject C constantly used a mouthstick that he readily accessed via a wheelchair-mounted holder. Subject B reported that the gripper did not always hold the fork tightly enough. The need for a task to retrieve and return the mouthstick and phone receiver was questioned because assistive technology is presently available to accomplish these activities. As a result of the pilot study, drink retrieval and paper filing tasks were added to the system. Accessing books and manuals was also identified by the subjects as being vocationally important if they were to rely on the DeVART™ to perform a job.

Table 1
Characteristics of Subjects

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Age</th>
<th>Lesion Level</th>
<th>Time Since Injury (Years)</th>
<th>Robotic Experience</th>
<th>Computer Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>49</td>
<td>C4-5 (complete)</td>
<td>&gt;10</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>B*</td>
<td>51</td>
<td>C4 (complete)</td>
<td>5</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>C</td>
<td>32</td>
<td>C4-5 (complete)</td>
<td>4-6</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>C4 (complete)</td>
<td>4-6</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

*Subject uses a ventilator.

Table 2
Subjects' Rating of Task Usefulness

<table>
<thead>
<tr>
<th>Task</th>
<th>Essential</th>
<th>Useful</th>
<th>Not Useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place page left/right.</td>
<td>A</td>
<td>B, C, D</td>
<td>—</td>
</tr>
<tr>
<td>Retrieve mouthstick</td>
<td>D</td>
<td>A, B</td>
<td>C</td>
</tr>
<tr>
<td>Select/load/return disk</td>
<td>A, B, C, D</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Dispense candy or pill</td>
<td>A, B, D</td>
<td>C</td>
<td>—</td>
</tr>
<tr>
<td>Deliver fork</td>
<td>C, D</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Retrieve telephone receiver</td>
<td>B, C, D</td>
<td>A</td>
<td>—</td>
</tr>
<tr>
<td>Environmental control unit</td>
<td>A, D</td>
<td>B, C</td>
<td>—</td>
</tr>
</tbody>
</table>

Though all four subjects liked the voice recognition interface, the desktop and VOTAN microphones presented problems involving speech recognition quality and interference from extraneous background noises. The frequent recognition errors and the need to repeat some commands were disturbing to all subjects, especially Subject B, who uses a ventilator. On the basis of these findings, a Shure® noise-cancellation microphone was tried with the system; it helped to improve voice recognition capability and minimize interference from background noise. It is now provided as the recommended microphone option for use with the system during the multicenter evaluation.

Although basic personal computer literacy skills would be useful, a therapist with no prior computer experience could learn to operate the system and serve as a trainer in 8 to 16 hr. On-site biomedical engineering staff members proved adequate for diagnosing a faulty encoder in the gripper and faulty hard drive in the Compaq computer. Developer and manufacturing support were required to recalibrate the robot nesting program, resolve a tracking problem, and program the two additional tasks, drink retrieval and paper filing. On the basis of input from staff members and subjects, the technical and training manuals were updated and revised for clarification.

Because of the user profile for this system, the subject pool was limited. Though statistically small, the group...
provided a good representation of intended users and a range of backgrounds. Although the pilot study revealed the need for some improvements in the DeVAR™ system, additional study is required to explore further vocational applications. Presently, the workstations are undergoing clinical evaluation at Veterans Administration Medical Centers (VAMC) in Brockton/West Roxbury, Massachusetts, and Seattle, Washington. The Seattle center will use the expertise and resources of the Assistive Technology Center at the Resource Center for the Handicapped (RCH), a vocational training institute for persons with disabilities. Designated staff members from Seattle VAMC and RCH will collaborate on the evaluation project. Only through this technology transfer mechanism can the system’s practicality, clinical utility, cost-effectiveness, and commercial readiness be best determined.

Due to the estimated cost ($85,000) of the workstation, most systems would likely be purchased either through governmental agencies or by private sector employers. Independence Works, Inc., in Stanford, California, has been selected as the commercial manufacturer of the DeVAR™ workstation. In a related Veterans Administration-funded research project, the Palo Alto Veterans Administration RR&D Center and SCI Service are using the DeVAR™ system as part of a vocational training facility for persons with high-level quadriplegia.

Implications

As this and other human service robots become commercially available, the final measure of user acceptance will come only from prolonged operation of these devices under actual living and vocational conditions. Robotic aids should be easy to set up and maintain, user friendly, flexible, and affordable. The ultimate goals for these robots are to give persons with severe mobility impairments expanded access to their environments at the time of their choosing, to improve their self-esteem, to make greater use of their mental talents, and to permit their entrance into the mainstream work force.

Acknowledgments

We appreciate the guidance of the late Robert W. Hussey, M.D., Chief, SCI Service, Veterans Administration Medical Center, Richmond, Virginia. During the course of the pilot study, Dr. Hussey died. It is for his foresight and dedication to the many projects that explored technologies for the benefit of persons with SCI that he will be remembered and missed. We thank the four veterans who dedicated their time and energy to the project. This work has been sponsored by the Department of Veterans Affairs, Rehabilitation Research and Development Service, under the leadership of John W. Goldschmidt, M.D., Director.

References


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