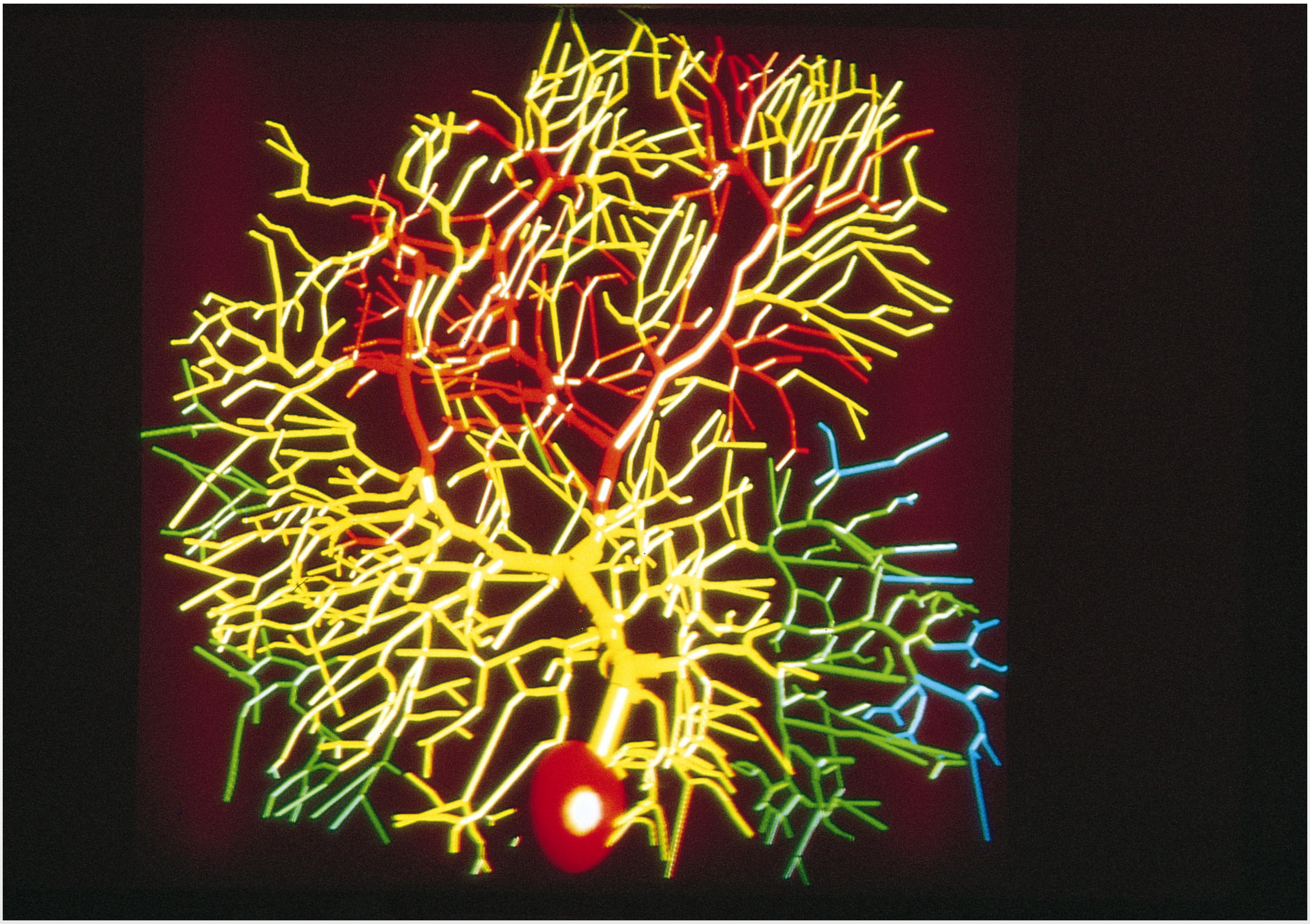

artn (http://www.artn.nwu.edu/VP/EarlyMedical/index.html)

Walter J. Greenleaf

Applying VR to Physical Medicine and Rehabilitation

The field of VR is still at the proof-of-concept stage, yet there is a growing number of potential clinical applications in the fields of physical medicine and rehabilitation that make effective use of VR technology. Previously, our research group has theorized that the rehabilitation process could be enhanced through use of VR technology. At the time, VR technology was too expensive for effective use in a clinical setting. Now that the cost for VR technology has decreased, the implementation and verification of this concept has begun in earnest.

VR Technology for Functional Evaluation of Human Movement

The determination of clinical impairment begins with a detailed physical examination and functional testing of the patient. The physical examination is designed to determine the presence of pain and any loss of strength, sensation, range of motion, and structure. The results are combined to produce a numerical assessment of impairment used to evaluate the patient's progress over time. Examinations and calculations can be time-consuming, expensive, and subject to observer error. Functional evaluation is currently accomplished by subjective observation of patient performance on standardized tests for motor skills. However, reproducibility of measurements becomes an issue whenever different examiners evaluate the same patient, which makes it difficult to evaluate a patient's progress over time.

The more objective assessments of upper extremity motion fall into two categories: visual and effective. Visual methods involve digitizing and estimating a visual record of the motion—the patient is videotaped performing a task, then the individual frames of the video are digitized and evaluated to quantify the degree of motion of the joint under study. The main limitation of this technique is that the camera can view motion in only two dimensions. In order to accurately assess movement in the camera's visual plane, the third dimension must be held constant, that is, the person must move along a known line parallel to the plane of the film in the camera. In most cases, the examiner cannot maintain the correct orientation even for short periods, making this a difficult and cumbersome technique. Effective methods measure the motion's effect rather than the motion itself. A work simulator is one example of an effective assessment tool. Work simulators measure the force exerted by a person on a variety of attachments that simulate tools used in the workplace. A major limitation of this approach is that no data is collected on how the person affects the force.

Ideally one would like to collect and compare range-of-motion data for a joint in several planes simultaneously while specific tasks are being performed by the patient, an impossible measurement using a standard goniometer (an instrument for measuring angles). Our research group has explored using a VR interface device—the DataGlove—as a means of collecting dynamic functional movement data. However, migrating the DataGlove technology (Figure 1) from the field of VR to clinical evaluation posed several problems. For example, during manufacture of the DataGlove, the treatment of individual bend sensors is not identical, making it impossible to characterize and reliably reproduce their behavior. Moreover, empirical observations show sensor hysteresis (memory effect), making repeated measurements irreproducible and making it difficult to determine the accuracy of the measurements. For highly accurate measurements, it is important to have a perfect fit of the glove, since poor placement of the sensitive areas of fibers yields incorrect measurements. Achieving a perfect fit posed a serious challenge due to the variability of hand shapes and sizes across a given patient population. With the goal of obtaining accurate, dynamic range of motion data for the wrist joint, our engineering group investigated other sensor materials and developed the glove-based WristSystem. Fiberoptic sensors were replaced by dual axis electrogoniometric sensors inserted into machine-washable lycra gloves that fit different size hands.

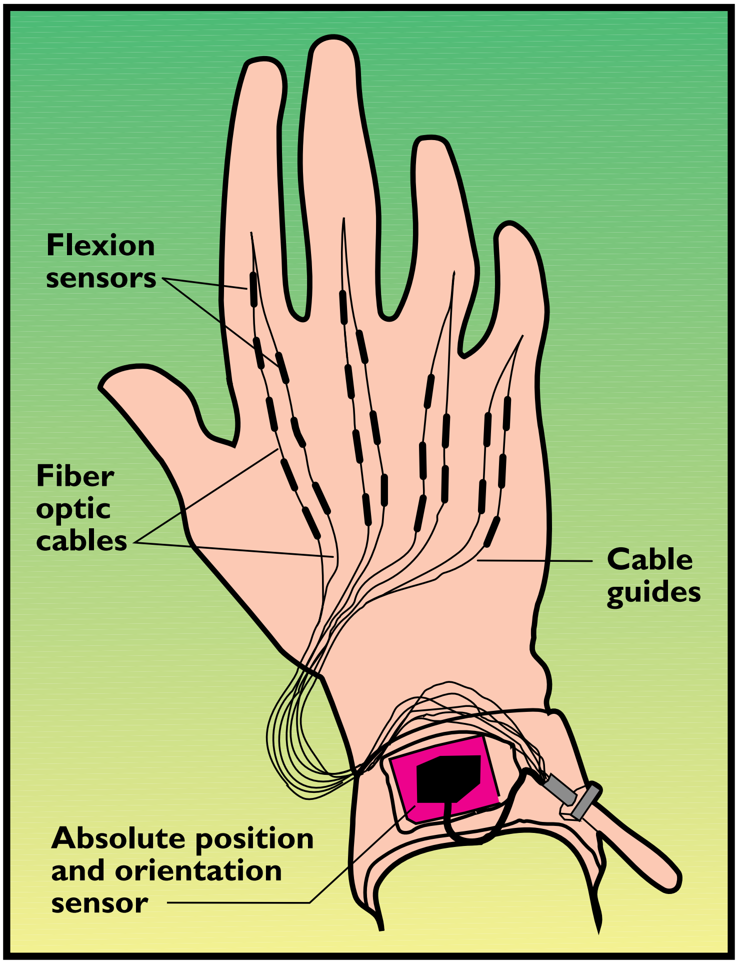

Figure 1. The DataGlove—derived from VR interface technology

The WristSystem is currently being used to track flexion, extension, radial and ulnar deviations of the wrist while patients perform routine tasks. A portable, lightweight DataRecorder worn in a waistpack permits the patient to be ambulatory while data is being collected at the clinic or work site; no visual observation or supervision is required beyond the initial calibration of the glove sensors. Real-time visual and auditory feedback can also be used to train the patient to avoid high-risk postures in the workplace or at home.

The WristSystem includes Motion Analysis Software (MAS) for the interpretation of the dynamic movement data collected over several minutes or hours. This software offers rapid, quantitative analysis of data that includes the total and percent time the wrist spends at critical angles; minimum, maximum, and mean wrist angles in four directions; the number of repetitions; and velocity and acceleration data. Figure 2 shows a sample plot of some of this data. In this example the patient's right hand was ulnar-deviated greater than 15 degrees for 84% of the time a certain task was performed.

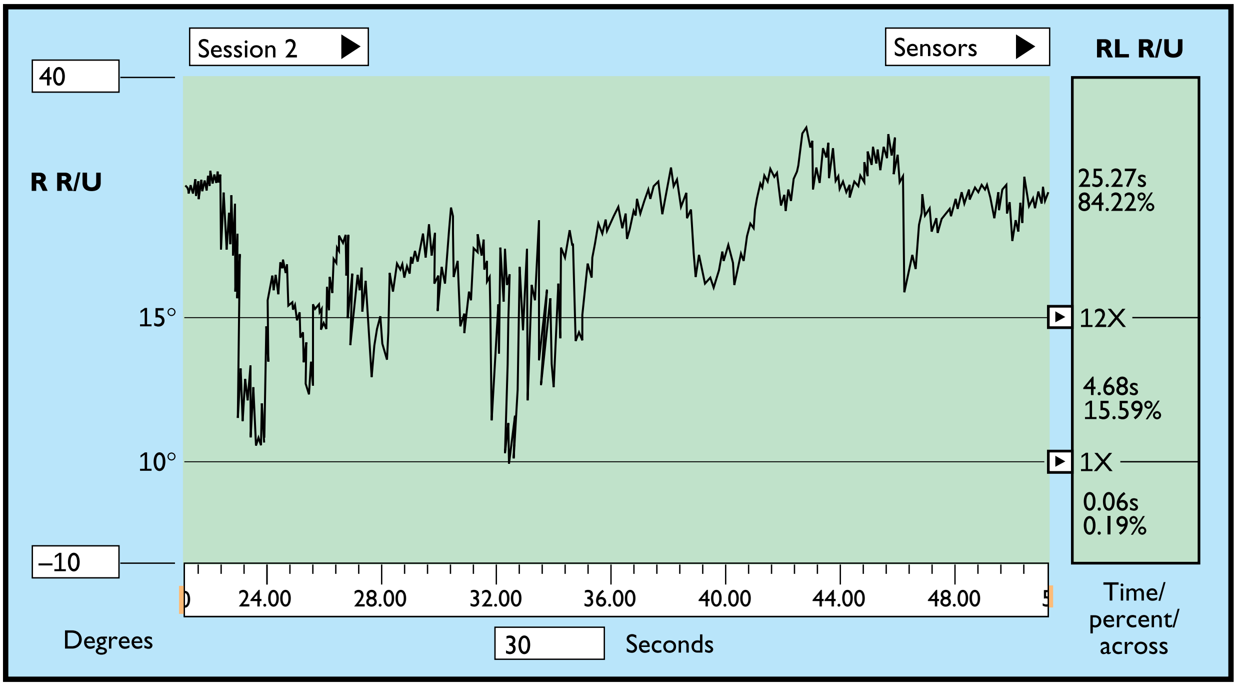

Figure 2. Real-time acquisition of range-of-motion measurements using the WristSystem

The WristSystem is currently being used by occupational and rehabilitation medicine specialists (M.D.s, P.T.s, and O.T.s), ergonomists, industrial safety managers, biomechanical researchers, and risk management consultants. The ultimate extension of this project is to build an augmented reality environment for quantitative evaluation of functional tasks. The system will link multiple input devices or sensors worn by the patient and 3D modeling software. Therapists will be able to design a virtual world composed of objects traditionally used in functional assessment tests, such as balls, cubes, keys, and pencils. The therapist will be able to record motion, the location and trajectory of the user's hand that is required to accomplish the motion, and any associated hand tremors or spasms. Once the data is collected, the therapist can interpret it using statistical analysis software. The clinician can also elect to review the motions by animation of the data and to change the orientation to study the motion from another angle.

Other control devices originally developed for VR are being improved and applied to the field of functional evaluation of movement in a variety of ways. Grigore Burdea [1] describes a system that would couple a glove with force-feedback devices to rehabilitate a damaged hand or to diagnose a range of hand problems. He describes another system under development incorporating tactile feedback in a glove to produce feeling in the fingers when virtual objects are "touched."

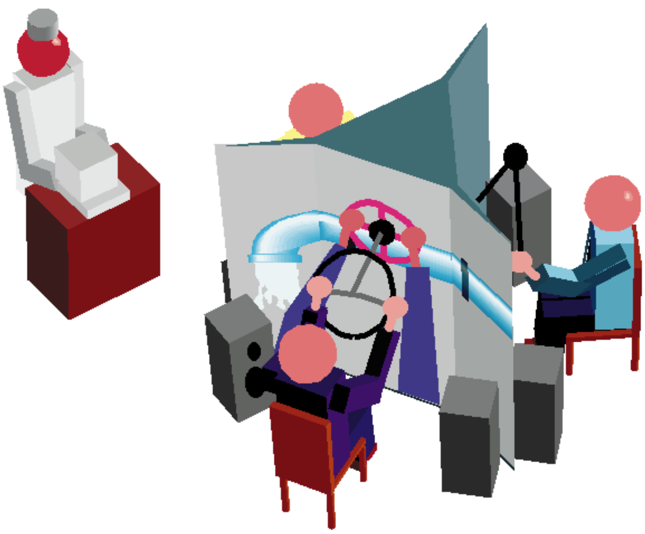

Figure 3. A proposed VR Rehabilitation Workstation: VR simulating a variety of occupational tasks of everyday living. A large 3D display provides visual feedback, while standard work-simulator technology provides resistive feedback.

VR Technology and Rehabilitation

Our group has theorized that both the neuro and orthopedic rehabilitation process can be enhanced through the use of VR technology [2]. Perhaps the most significant advantage is that a single, VR-based rehabilitation workstation could be easily customized for individual patient functional rehabilitation needs. We are currently developing some basic components for a VR-based workstation (Figure 3) that will be used to:

- Restructure the rehabilitation process into small, incremental functional steps
- Make the rehabilitation process more realistic and less boring, enhancing patient motivation and recovery of function
- Facilitate home rehabilitation
- Provide an objective index of function for activities of daily living and work

The VR rehabilitation workstation uses VR technology to bring a feeling of "immersion" and realism to rehabilitation protocols. A clinician provides a variety of artificial environments to facilitate rehabilitation—ranging from very engaging and interesting (when motivation is important) to very realistic (when functional or work-related tasks must be emphasized.

The Role of VR in Disability Solutions

One exciting aspect of VR technology is the inherent ability to enable individuals with physical disabilities to accomplish tasks and have experiences they would otherwise be denied [2]. There are approximately 35 million people in the U.S. with physical disabilities affecting their ability to work in certain types of jobs. VR technology may provide an adaptable mechanism for harnessing a person's strongest physical ability to operate an input device for a computer program.

One system we have developed is based on DataGlove technology. The system allows users to record custom-tailored gestures and to map these gestures to actions. These actions can range from a simple command, such as a mouse click on a computer screen, to more complex functions, such as controlling a robotic arm. An application programmer can define the functional relationship between the sensor data and a task with real-time graphical representation on a computer screen. Simple gestures can be translated to a preprogrammed set of instructions for speech or movement.

The prototype GloveTalker is an example of one-to-one gesture mapping to a computer-generated action that provides additional communication skills to people with vocal impairment. The patient is able to speak by signaling the computer with a personalized set of gestures while wearing the DataGlove, which recognizes hand positions (gestures) and passes this information to the computer's voice-synthesis system. For example, a user may map a specific gesture, such as a closed fist with one finger partially extended, for the phrase "Hello, my name is Susan." The computer has some freedom in interpreting the gesture so people capable only of relatively gross muscle control may use the system. By mapping the gestures to the alphabet, complex communications becomes possible to individuals that would otherwise be "locked in." There is also the possibility of sending the voice output through a telephone system, enabling vocally impaired individuals to communicate verbally over distance.

Conclusion

VR tools and techniques are rapidly developing in the scientific, engineering, and medical areas. Although traditionally used as input devices for virtual worlds in the entertainment and defense industries, sensor-loaded gloves may become the clinical tools of choice to measure, monitor, and amplify upper-extremity motion. While we have identified other potential clinical applications, many technological challenges must be met before such devices can be made available for patient care.

Pioneers in the field of medical VR are encouraged to design sophisticated devices that promote both physical and psychological gains for injured and disabled patients while keeping costs for these devices within an acceptable range for healthcare providers and third-party payers. The mandate is complex, but like VR technology itself, the possibilities are promising and exciting.

References

1. Burdea, G., Zhuang, J., Roskos, E., Silver, D., and Langrana, N. A portable dextrous master with force feedback. *Presence 1*, 1 (Winter 1992), 18–28.
2. Greenleaf, W.J., Tovar, M.A. Augmenting reality in rehabilitation medicine. *Art. Int. Medicine* 6, 4 (1994), 289–99.

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