# ICAT '92

# FEEDBACK TECHNOLOGY AND VIRTUAL ENVIRONMENTS

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**ABSTRACT:**

The evolution of input devices has been caused by an evolution in computer software and hardware capabilities. Mainframes moved aside for the ubiquitous PC which has evolved into the desktop workstation. Concurrently, tables of numbers evolved into graphics and ultimately 3-D images which are animated and can be modified in realtime. Along with this increased capability was an increase in the number of parameters to be manipulated. Initially an array of devices were added until the power users desk resembled a child's busy box with as many knobs, dials, touch pads and other positioning devices as there was room. The computer and software manufacturers were faced with two choices: build bigger desks and clone more arms for power users, or develop more capable and adaptable input devices and take advantage of humans natural dexterity and coordination. Luckily for the users, economics and common sense pointed towards developing advanced input devices.

The link between the human sensory motor system and the computer is either a barrier to productivity or a natural conduit through which information and experiences flow. Feedback technology is ready to become the link which will begin the evolutionary process of closely coupling the human system with the computer. In the near term these evolving technologies can be used to solve real world problems in many application areas including business, medicine, design, and entertainment.

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Dr. Marcus is President and founder of EXOS, Inc. Her activities include setting strategic direction for the corporation, fund raising and managing the R & D and product development activities.

EXOS, Inc. is a medical measurement and rehabilitation equipment company. Our strategy is to become a leader in this field with technically dominant systems that address existing customer needs for much more accurate and productive methods of assessment and record keeping. The key technologies are derived from advanced development research, funded by NASA and other agencies, in robotics and virtual environments. Our current research is directed towards developing feedback technologies for control of dexterous robots and virtual environments. Prior to founding EXOS, Inc. Dr. Marcus was a member of the Product Engineering Unit of the Engineering Sciences Section of Arthur D. Little (ADL), Inc. The major focus of her work was in the design and development of medical products and advanced robotics technologies.

## INTRODUCTION:

There are many aspects to the need for Feedback devices. Imagine trying to pick a flower or grasp an egg with one eye closed (no depth perception) and heavy gloves (virtually no feeling in the hand you are using). That is precisely what we are doing in our current computer applications which are 2-D or pseudo 3-D and use a keypad, mouse, or other pointing technology. Virtual Environments (VE) today provide a good visual context, yet little or no tactile and kinesthetic feedback. In order to provide a context for considering these devices this paper describe the kinds of problems they could uniquely solve, then describe the current technology, and finally provide a vision of how and when this technology will be available to solve real world problems.

## APPLICATIONS:

The applications that Feedback technology could enhance are as varied as the applications of 3-D graphics or high speed computing. The following sections describe a few applications which could be important in the near future.

### Business:

In the evolving world of global business it is becoming more important to be able to communicate with customers, co-workers, suppliers, and others in a higher and higher fidelity manner. Imagine that you're a design engineer in the US working on a product which has a critical part to be injection moulded in a factory in another country. The moulders are having a difficult time making the part to your specification and you don't want to change certain critical aspects of the part because it will require significant redesign of the components which fit into it. The answer? Grab the prototypes, CAD files and drawings and jump on a plane. Right? Well I believe that any product development engineer in their right mind would prefer a teleconference. But without seeing, touching, and feeling the product and jointly experiencing the options it is possible that miscommunication will occur. If you and the overseas engineer could poke at the design, explore the tolerances, and manipulate the object in real time together you could be sure that the language and distance barriers would not cause costly misunderstandings.

Imagine trying to understand a customers feedback on a new product. For example, you're a tool manufacturer designing a hand held power tool for a factory to change the angle of use to reduce the incidence of Carpal Tunnel Syndrome. If you and your customer could both hold the virtual product, feel its weight distribution, and see how the customer uses it you would be able to respond to their need faster. This would avoid costly design iterations and ensure the product really solved the problem without creating new difficulties.

In business the feedback devices are a facilitation technology which makes it possible to communicate more easily and completely, and at a lower cost than taking the time to visit the customer every time you might improve the design process by doing so.

### Medicine:

You are a medical student now, or a practicing surgeon trying to learn a new laporoscopic surgical procedure. Using Today's technology you would watch videos, observe procedures and practice on cadavers. The instructor might say feel this, its the gall bladder, now feel this, this is a structure you should avoid with the laporoscopy tools. The first time you did the procedure on a patient it might take several hours, later maybe only one or two hours.

Now imagine attaching some sensors to the ends of the probes inserted into the patient. The surgeon wears a stereo display and so do all the students. The surgeon operates the tools which are inside the patient with masters worn on or held in his hands which sense his motions. The surgeon instructor can do the procedure once under normal conditions and as fast as desired while narrating a description of the operation. The students can then play back the recorded data as many times as they wish, as slowly as they wish, allowing the instructor to guide them through the procedure. If the students wear or hold masters driven by motors their hands can be made to move the way the surgeon instructors did. If a sufficient data base has been created the students can try the procedure by themselves and practice until they score as well as the instructor for accuracy and speed. Much of what makes a surgeon skilled is a trained sense of touch therefore the key to making VEs useful is to make them feel real.

**Entertainment:**

By now most people have experienced something similar to VE technology in entertainment. Amusement park rides like "Back to the Future" at Universal Studios surround you with a visual image that looks real and shake the customers using a motion platform synchronized to the images. Some of them even blow air at the passengers to make it feel as if air is rushing by as the passengers speed forward. Hard Drivin by Atari is an arcade game that uses force feedback to the controls in addition to a motion base and a surround visual to make the passenger feel the pull of the road as they drive a race car around the course. Entertainment and games could use Feedback technology too. Imagine a game or ride which takes you to the surface of Mars by allowing you to control a robot which is collecting scientific samples. You feel the soil running through your fingers as you grasp a hard shiny object. What about a virtual trip to the deep ocean where you control a robot salvaging objects from the titanic. The opportunities in entertainment are as much fun as they are limitless.

**Teleoperated Robots in Space:**

What do robots in space have to do with VE's or Feedback technology? Already researchers are beginning to use VE's as a tool to compensate for time delays due to the distance between the operator and the worksite. If you are on earth and controlling a robot doing repairs on the Space Station there will be an 0.25 second delay between the time you send a command and when the robot receives it. If the robot is on the moon the delay could grow to approximately a 3.0 seconds. In the control of a robot a few seconds delay could cause instabilities in the system performance. Imagine a diving board; get it bouncing, time it right and the board meets your feet and accelerates you in the direction you want to go in, time it wrong and you feel like you've crashed into a brick wall with your feet. It is the same with the robot. Depending on what the signal tells it to do it can overshoot, crash into objects, or miss them all together. These problems can be overcome by building a virtual environment exactly like the real world except without the time delay and using it to control the real robot.

**CURRENT STATE-OF-THE-ART:**

Feedback technology has been evolving concurrently with the complexity of the applications and displays. The development of advanced input devices began with trackers which provide information regarding position and orientation in space information. Then came whole hand motion sensing devices which measure position and orientation in space plus the motion of the individual digits and in some cases the individual link segments of the fingers. Feedback masters which built on the motion sensing capabilities of the whole hand devices by adding tactile or force feedback were then developed. After the whole hand motion devices, development diverged into general purpose Feedback devices and special purpose feedback controllers designed to solve a specific problem or set of problems.

**Trackers:**

Trackers measure the position and orientation of a sensor implanted object with respect to another object. The objects contain an array of transmitters and receivers depending upon the technology used. The three most widely used types are described below. When incorporated into a mouse or wand, they can be used to select and move objects within a 3-D environment. Functions such as object stretching and twisting can be accomplished by adding software constraints.

The Polhemus™ is an AC magnetic device which measures 3-D position and orientation in space. It has been used extensively in VE and related applications. The disadvantage of the Polhemus is its speed and sensitivity to ambient noise created by metal objects and magnets. The Bird™, by Ascension uses a DC magnetic field. Its update rate is significantly higher than the Polhemus, and it is much less sensitive to ambient noise. Ascension has also produced versions of the product that work over a much larger volume and one which supports multiple users simultaneously. The Mattel PowerGlove™ and the Logitech Flying Mouse™ use ultrasonic measurements. Ultrasonic devices can be very accurate and are usually low cost. However, the line of sight between the transmitter and receiver must not be obscured. New entries into this field are a Gyroscopic device from GyroEngine and another magnetic device currently under development by Piltdown which claims to overcome the limitations of the existing magnetic devices.

**Whole Hand Motion Sensing:**

To perform a dexterous operation such as moulding an object, manipulating something in your fingertips, or grabbing an object in a particular orientation, finger motion as well as position and orientation must be measured. Whole hand motion sensing devices allow you to do just that and more, including identifying hand gestures and postures which can be given a symbolic meaning within a program.

In recent years several glove mounted sensor systems have been developed for measuring hand motions. The most widely used is the VPL DataGlove™ which utilizes a fiber optic sensing system sewn onto a lycra glove. The system is light weight and unobtrusive to the user but has a limited sampling rate (60 Hz), and exhibits accuracy and reproducibility problems (Wise et al, 1989). The accuracy of glove designs is reduced because as the hand moves, the glove stretches and shifts on the hand; thus the sensors shift with respect to the skeleton. In addition the attachment system used in the DataGlove mechanically couples the optical sensors so that flexing a given joint affects readings from adjacent joints. Gloves also do not fit all users similarly, therefore the sensor performance on one user may be different than others. In combination with a 3-D tracker, which provides the position and orientation of the hand in space, it can provide basic gestural information to VEs.

A new glove design is the Virtex CyberGlove™ (Kramer and Leifer, 1989). It uses a foil strain gauge technology to capture joint movements. The strain gauges themselves seem to have a better dynamic range and precision than the fiber optics, and are mounted so as to minimize the influence of stretching and twisting of the glove on the output. It shares both the comfort benefits of other glove systems and improves on the sizing disadvantages by removing the glove fingertips. This product incorporates wrist bending sensors and a sensor interface box with a serial connection, and can also be used with a 3-D tracker.

For high precision finger joint motion sensing and a full 20 DOF (three bending plus one side-to-side per finger) the EXOS Dexterous Hand Master™ (DHM) can be used. It uses Hall-effect sensors to measure the angle between two links which are attached to the individual finger segments. The attachment system is designed to fit virtually all human hand sizes and shapes throughout their full range of motion comfortably. It has high accuracy, better than 1° in most flexion ranges (Makower et al, 1990), and includes thumb circumduction as well as ab/adduction of each of the fingers. Glove designs have attempted to provide this capability by measuring finger separation which is not independent of other finger motions. The price to pay for the precision of the DHM is that it takes a few more minutes to put on than a glove and weighs about 15 oz. This weight is most noticeable when making rapid hand motions. The DHM has been used in conjunction with 3-D trackers. Wrist flexion and radial/ulnar deviation (side to side motion) sensors are also made by EXOS.

**Feedback:**

Imagine trying to insert a key into a lock without being able to feel the key hitting the opening. That is what most VE systems feel like today. Providing touch and kinesthetic feedback is the key to enabling users to accomplish useful tasks with VE. The developments in this area have diverged into two distinct categories; Feedback Masters which are general purpose devices and Feedback Controllers which are designed for a specific application or class of applications.

Feedback Masters:

The TouchMaster™ from EXOS is a non-reactive, tactile feedback device which uses miniature voice coil displays. The TouchMaster can be combined with the DHM, or any whole hand motion sensing technique. Experiments with this concept have shown that tactile feedback can achieve performance improvements comparable to force feedback in some scenarios (Patrick, et al 1990). It can also significantly improve performance where visual information is degraded. It is an inexpensive and light weight way of improving VE performance by adding contact and stiffness information.

In an effort to provide edge discrimination and slip information, TiNi Alloy Company has developed a tactile array using shape memory alloy actuators. These arrays poke your finger tip in a different location depending upon what is happening in the VE. While in concept the idea of an array display is interesting the SMA actuators are neither forceful nor rapid enough in their current embodiment to effectively display the desired information. They are however an important step in the evolution of this technology. To take advantage of array displays, basic research in perception of touch and force needs to be conducted.

Articulated Devices:

The objective in implementing articulated devices (ADs) as a method of interacting with computers is to provide additional types of feedback, as well as position, to the user. A body of knowledge on the influence of different feedback modalities on task performance has been developed primarily in conjunction with teleoperation of manipulators. Systems linking an operator with a manipulator employing a variety of direct mechanical, electric motor, hydraulic, or pneumatic transmission/actuation schemes, have been used and studied since shortly after World War II (Sheridan, 1989). The original systems were direct mechanical linkages which allowed the operator to be behind leaded-glass walls and were used for handling radioactive materials in nuclear research laboratories. Shortly thereafter, servomechanisms and electrical or radio links were added to move the operator even farther from the manipulator. Early systems without direct mechanical links had serious drawbacks because they did not enable the operator to feel what the manipulator was feeling when it performed the task. Operators would often apply too much pressure, breaking objects, or too little, dropping them. Fortunately for the operators, systems began to be developed which provided force feedback. As computer capabilities improved, the ability of these devices to provide accurate and rapid feedback and control has improved. Recent master-slave systems for arm (Bejczy and Salisbury, 1983) and hand (Jacobsen et. al, 1989) manipulation provide good controllability and insight into what feedback is necessary for adequate task performance.

The current teleoperation technologies are generally bulky and only interface well with selected classes of manipulators. In an effort to adapt this technology to general purpose computer interfaces, several groups have been conducting research or developing hardware. Kilpatrick (1976) set up a system using a large force-reflecting master originally designed to control a robot arm, for computer-aided task interaction. The arm master has been used experimentally to assist biochemists is studying drug/substrate interactions (Ouh-young, 1990) and has been found to significantly assist in task performance. This device is large and thus is not suitable for general purpose applications in a desk top environment.

Although there are a wide variety of commercially available master manipulators for controlling robot manipulators there are no compact commercially available feedback systems set up for computer input. Very few force reflecting systems have been developed for generating forces on the fingers and sections of the hand. Iwata (Iwata 1990) describes a system for the thumb, two fingers and the palm (Figure 1). The palm is actuated by a six DOF parallel stage driven by electric motors. Each section, the palm, the fingers, and the thumb are driven by electric motors. The system can transmit large forces to the hand and fingers but is limited to pinch type grasps because of the single DOF plates for the fingers. Initial applications areas reported were animation and CAD generated product prototype testing. This system is currently being developed further and tested.

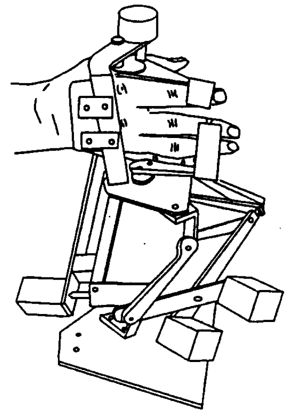

Figure 1: Tsukuba University Master

Burdea (1991) describes a system based upon pneumatic cylinders and the VPL DataGlove. This system uses pneumatic cylinders placed between the inside of the palm and the fingertips to generate forces. The system is compact and lightweight, but at present can only simulate grasp forces between the palm and fingertips. Contact of the fingers with objects supported externally cannot be simulated.

EXOS's Sensing and Force Reflecting Exoskeleton (SAFiRE) is an attempt to overcome the limitations of existing feedback masters and whole hand input devices (Figure 2). We are developing a comfortable, lightweight, field compatible, and affordable anthropomorphic force feedback master for teleoperation of dexterous robot hands and control of virtual environments. The main goal of this program is to provide accurate measurement and force feedback to the free moving hand without encumbering or restricting arm movement. An initial prototype has been built and tested with excellent results. This prototype has 2 degrees of freedom (DOF) and fits the index finger. It can apply a 1 in-lb torque at the proximal interphalangeal (PIP) joint and 2 in-lbs at the metacarpalphalangeal (MP) joint over at least 90° of motion. These torques are applied with a low friction, backdrivable, and stiff transmission and driven by DC motors.

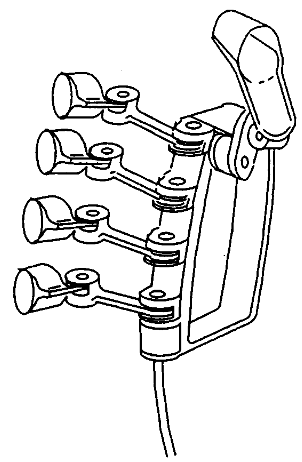

Figure 2: SAFiRE

Feedback Controllers:

AT&T Bell laboratories has developed a high performance, compact force feedback joystick (Figure 3). It was intended to support engineering, business, and scientific desktop computing applications. In addition it could be a much more effective interface for users with impaired vision of other sensory motor deficits. It is 7X4.5X2 inches in size, weighs approx. 2 lbs, can apply 75 grams weight to the end of the joystick (2 inches long), and can run at over 200 Hz. Its performance characteristics and utility is being studied. It has been demonstrated for navigating through an electronics CAD data base by setting the force to have a step jump at the edge of each trace. It is not yet in production, but could be within the reach of workstation or PC power users. It is fast enough to enable the users to feel textures, and provides enough force to give a good range of levels for different conditions. Once software packages provide capabilities which take advantage of this device and others like it, significant improvements in task performance will be realized.

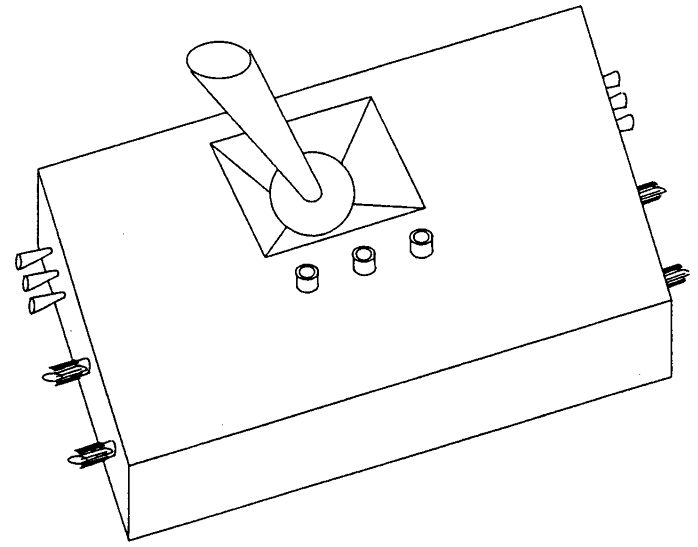

Figure 3: AT&T Joystick

The MIT CAD laboratory has developed a controller for sheet metal design which is like a mouse with a hinge in the middle (Figure 4). Although the first prototype did not provide force feedback, it could be easily implemented within the existing design. It uses a tracker and an angle sensor combined with a few mode shifting buttons. To use it you align the symbol on the screen with the part of the sheet metal to be bent and then bend the hinge until the desired position is obtained. If a motor were incorporated you could feel the deformation of the metal and be warned of material limitations or detect interferences with other parts. This device could evolve to a simple low cost answer to the problem of specifying complex shapes in CAD.

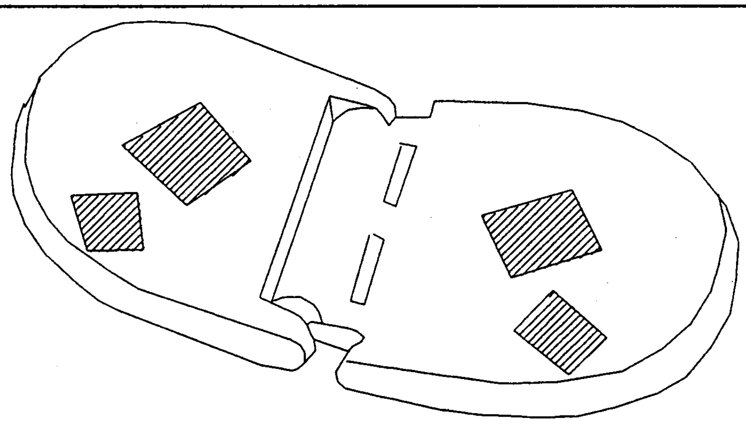

Figure 4: MIT Hinged Mouse

## CONCLUSIONS

Current Technology can be used to provide a wide array feedback types in a variety of forms. In order to fully utilize these tools we must select applications which have a clear economic or performance requirement for feedback. Then we can answer the critical research questions concerning what information and in what form it should be presented to the user. Once we have a better understanding of human performance and perception, we can use these tools to make VEs which provide enough information to the user to rapidly and effectively perform complex tasks.

## REFERENCES


Bejczy, A.K. and J.K. Salisbury, Controlling Remote Manipulators Through Kinesthetic Coupling, Computers in Mechanical Engineering, July 1983, pp.48-60.

Iwata, Hiroo, Artificial Reality with Force-feedback: Development of Desktop Virtual Space with Compact Master Manipulator, Computer Graphics,24,4 (August 1990),pp.165-70, Proceedings ACM SIGGRAPH '90.

Jacobsen, S.C., The State of the Art in Dextrous Robotics, Conference Dinner Speaker, IEEE International Conference on Robotics and Automation, May 1989, Scottsdale,AZ.

Kramer, James and Larry Liefer, The Talking Glove: An Expressive and Receptive "Verbal" Communication Aid for the Deaf, Deaf-Blind, and Nonvocal, Stanford University, Department of Electrical Engineering (1989).

Makower, Joshua, Mohamad Parnianpour and Margareta Nordin, The Characterization of the Dexterous Hand Master Index Finger In Flexion and Extension ( A Pilot Study), The Hospital for Joint Diseases, New York University Medical School, Technical note, New York, NY (1990).

Ouh-young, Ming, Force Display in Molecular Docking, Department of Computer Science, PhD Thesis (TR90-004), University of North Carolina at Chapel Hill (February 1990).

Patrick, Nicholas J.M., Thomas B. Sheridan, Michael J. Massimino and Beth Marcus, Design and testing of a non-reactive, fingertip, tactile display for the interaction with remote environments, Proceedings of the SPIE Symposium on Advances in Automated Systems, Boston, MA(1990).

Sheridan, Thomas B., Merging Mind and Machine, Technology Review, October 1989, pp. 33-40.

Wise,Sam, William Gardner, Eric Sableman, Erik Valanis, Yuriko Wong, Karen Glass, John Drace and Joseph Rosen, Evaluation of a Fiber Optic Glove for Semi-Automated Goniometric Measurements, Palo Alto Veterans Administration Hospital, Rehabilitation Research and Development Center, Palo Alto, CA (1989).