Multidivisional Graduate Education Program in Sensory Engineering

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Abstract

Sensory engineering is defined to be the science and technology of synthetic environments. This exciting and emerging discipline incorporates such technologies as virtual environments and virtual reality, data visualization, human sensory system modeling, human-machine interface, and perception, cognition and performance characterization. An educational curriculum requires basic science in the fields of computer science, electrical engineering, psychology, physiology, the biomedical sciences, and mathematics. We present the plan for a multidivisional graduate education program in sensory engineering, currently being developed at the Johns Hopkins University, within the Schools of Arts and Sciences, Engineering, Medicine, and the Applied Physics Laboratory.

1. Introduction

One of the most exciting and challenging new uses for computers is to build and interact with virtual environments (see [1] and [2] for example.) Various applications of virtual environments, to virtual reality (VR), robotic telepresence, teleoperations, and human sensory enhancements, captured public enthusiasm long before any true implementations were available. Combining high speed computers with input and output devices for human sensation, especially vision and audition, has produced a seemingly infinite potential for creating new worlds of realities for humans to experience directly, with little consciousness of the computer interface.

A 3D synthetic environment is constructed with a computer from numerical data. The data can be the output of a mathematical model of a physical situation, such as the dynamics of an aircraft flying over some terrain, an arrangement of solid geometric objects in a room or a region of space, or a geometric realization of some abstract multidimensional dataset, such as a time series of measurements of the state of the economy over a fixed period. Using various visual and auditory output devices, the human operator can experience and interact with the environment as if immersed in it.

Today's synthetic environments have limited sense of immersion. The state of the technology has been rather slow to advance. After a rapid and highly promising start, the development of the technology of synthetic environments has experienced major roadblocks, due in large part to high cost. As enabling technologies are developed and made affordable, however, new levels of progress are expected. More significant, however, are the gaps in our understanding of fundamental concepts and sciences of human sensation, perception, and experiential knowledge.

A science of synthetic environments is needed to fill those gaps and to create the enabling technologies. Dr. Kenneth Johnson of the Johns Hopkins University Department of Neuroscience has coined the term "sensory engineering" for the collection of disciplines that contribute to our basic understanding of what makes a compelling and immersive synthetic environment. In preliminary investigations of research interests within the Hopkins community, it became clear that throughout the various divisions, including the Schools of Medicine, Engineering, and Arts and Sciences and the Applied Physics Laboratory, the University has all of the components required to define and establish this branch of science. The great difficulty, however, is that the discipline is diverse and unwieldy; a program is needed to facilitate the collaborations and the multidisciplinary, multidivisional approaches necessary (See [3] for more details.)

2. What is sensory engineering?

Sensory engineering is defined as the science of synthetic environments. A synthetic environment, in turn, is defined as a 3D world constructed on a computer from real and mathematically-modeled data and presented to a human computer operator, so that the operator experiences some degree of immersion in the environment. The immersion could be total, in which all of the user's senses are deceived into perceiving the synthesized world as the real world. Sensory inputs created by the computer must be perceived by the user as realistic and all behavioral outputs from the user must be detected and converted by the computer into modifications to the synthetic environment. Such immersion would require a total level of interaction with the computer and its synthesized world.

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Significantly lower degrees of immersion can also fall under the domain of sensory engineering.

Figure 1 presents a simple model of the technologies and devices required for a human operator to experience and interact with a synthetic environment. The figure represents a human observer immersed in the real world. The human biological sensory system processes environmental data in the form of light, sound, heat, mechanical forces, and chemical signals, producing usable measurements of phenomena in the environment. Our biological neural processors somehow transform these measurements into internal representations and perceptions of the environment, which are then processed to produce information and to permit us to make decisions. Some of these decisions affect behavioral responses: actions or reactions to alter the environment, to modify the biological sensory system (e.g., a turn of the head to glance in a direction), or to create an internal reaction and modification to the perception or information processing systems.

This simple model can be modified by placing computational devices between the human observer and the environmental data. The computer intercedes in every interaction between the human and the environment. Thus, in Figure 2, a sensory interface produces the same set of signals to the biological sensor system as were present in the natural environment of Figure 1. Similarly, sensors, such as head and eyeball tracking devices, position and orientation detectors, datagloves and the like, are used to read human observer behaviors and actions to alter the environment. The synthetic environment is constructed from physical sensors of the real environment and from models to synthesize artificial or mathematical data about a geometric environment. The data undergo transformation into usable information for the creation of biologically-sensed signals. Similarly, the behavioral data sensed from the human observer can either be transformed into instructions to modify the synthesized environment for subsequent sensory input, or be transduced into signals to drive servomechanisms to alter the real environment. Figure 2 does not show the internal components of the human observer, although scientific investigations into cognitive processing of biologically-sensed data is also a critical part of sensory engineering.

We can also illustrate types of applications of synthetic environments by removing or modifying dataflows and components in the model of Figure 2. Applications to VR, sensory enhancement, environmental overlays, and robotic telepresence are presented. Other applications can be similarly modeled.

VR totally removes the physical environment from the system; the entire environment is computer generated. We illustrate VR by removing from the model in figure 2 the modules for the physical environment and the physical sensors and the transducers which permit interaction with the physical environment. In the perfect system, the human observer would not be able to distinguish the VR experience from that of the real world. There could be points of confusion, for example, if the environment were specifically created to violate perceived laws of nature. VR is totally immersive. Current technology has yet to produce a true VR system. Data visualization applications would follow the same variation on the model, except with lesser degrees of immersion.

Sensory enhancement is an application of synthetic environments in which signal conditioning algorithms are applied to sensory data from the real environment. The system does not inject synthetic data into the environment nor use observer behavior to modify the physical environment. Thus, in the model, synthetic data sources and transducers modules are removed from the system. In this application, signal processors are introduced to filter, enhance, or otherwise modify the signals from the physical sensors. An example of this application is the Low Vision Enhancement System (LVES), designed by one of the authors (Massof, see [4]). Here, a visually-impaired human observer wears a device that senses visible light through the lenses of television cameras. Image processing modifies the camera image, by edge detection, contrast enhancement, or more sophisticated processing effectively to compute an inverse transform of the visual degradation to compensate for the effects of the poor vision.

The concept of environmental overlays is a natural extension of sensory enhancement . Along with the conditioning of signals derived from the physical environment, the computer synthesizes additional data to inject into the environmental database. This is represented in the model by removing the transducers component. An example of such an application is an airplane maintenance head-mounted display system. Maintenance workers wear special goggles onto which are displayed blueprints or circuit diagrams of electronics or other subsystems beneath the surface of the airplane. This information is extracted from the appropriate database and overlaid onto the transparent goggles, using head tracking to keep the diagrams superimposed on the appropriate part of the airplane skin.

Sensory engineering also encompasses robotic telepresence. Figure 2 presents a model of this type of application. The environment, however, is remote---the human observer is not in direct contact with the environment---and the dataflows connecting the physical and virtual environments are therefore over longer distances. Applications include remote teleconferencing, in which the observer is present at a remote conference in all but body, or the use of robotic agents in dangerous situations, such as nuclear power plant maintenance, fire fighting, planetary probes, or unmanned weapons systems.

3. Science of synthetic environments

The disciplines of sensory engineering include not only the expected fields of engineering and computer science, but also medicine, physiology, mathematics, psychology, and the cognitive sciences.

The human visual system can sense a field of view of approximately 120 degrees at a resolution of about 1 second of arc. Thus, a digital display for a head-mounted output device should be able to accommodate roughly 7200 pixels square, or 52 million pixels. At a video rate, this device should present 30 images per second, for a rate of 1.5 billion pixels/second. With two displays (left and right eye images), the display device requires a software architecture and driving computer capable of producing 3 Gpixels per second, simply to maintain realistic imagery. Further, to produce animated complex geometric objects for presentation in real time to the displays requires significant advances in computational geometry algorithms and data structures.

The primary components of the synthetic environments system must generate signals for the biological sensory system and the detect and process the human observer's behavioral responses. Thus, a fundamental area of basic science needed is in the understanding of the human sensory systems and how these systems receive and process data. Although the model includes all five of the basic sensory systems, the visual, auditory, and haptic systems have occupied most of the research and development effort. If one considers only that which is necessary to achieve some specific application rather than aiming for total immersion, it is clear that a sufficient feeling of experiencing and interacting with reality is achieved by what one can see and hear and touch.

In addition to these primary senses, however, humans have more subtle sensory systems which are important for developing a compelling feeling of immersion in an environment. The vestibular system, for example, provides us with a sense of balance (and sensation of off-balance) and a sense of motion. In fact, a principle component of simulator sickness (a form of nausea felt, for example, with prolonged use of head-mounted display systems) is due to a conflict in sensation between visual inputs which imply that one is in motion and vestibular system inputs which imply that one is stationary. The somesthetic sensory system has a proprioceptive subsystem that provides an internal sense of the state of the body, such as the positions and angulations of the limbs and joints and the tensions of the muscles and tendons. Moreover, inconsistencies between expected proprioceptive responses to physically fatiguing behaviors, such as marching uphill carrying a full backpack, and the actual feelings experienced in a virtual reality, can limit the effectiveness of VR for training.

The sciences of characterizing biological sensor processing and performance are certainly essential for the design of effective synthetic environments; however, the greater success of such a system is assured with the human operator's perceptions of the reality. The components of the model that have been treated as a black box---the perception, information, and decision-making processing which is internal to the human observer---are probably the most important parts of the process to understand. How the human operator converts outputs from the biological sensors into perceptions determines the functional requirements of the interfaces. The problem is further complicated because this conversion process is context sensitive. As an example, the current technology for VR-type games in arcades is relatively primitive; the graphics are cartoonlike, the head tracking has limited resolution and latency, the display resolution is coarse, colors are unnatural, and tactile feedback and audio directionality are limited. Yet, most users of VR arcade games appear to accept the reality posed with a reasonably large feeling of immersion. Game players willfully suspend disbelief. Significant interest in the application affects the perception of reality.

To summarize, scientific issues for the disciplines of sensory engineering include the characteristics and performance of biological sensors; the psychology of human perception and sensory information processing; the physics, physiology, and psychophysics of sensory interfaces and behavioral responses; the sciences of sensing and interpreting observer behavior; the mathematics of data synthesis and fusion; cognitive and mathematical theories of data transformation for sensory information vectors, feedback and control, and data visualization; advanced algorithms for computational geometry and real-time signal processing; and human/machine systems analysis and engineering.

Historically, the field of synthetic environments has been defined by the software and devices for generating, presenting, and interacting with computer graphics. This was reasonable because at a fundamental level, as a technology, the primary purpose was to develop new and innovative methods for human-computer interfaces. Enabling technologies are defined by the components for interfaces with the computer and for the computationally intensive processing required for immersive interaction with a three dimensional world constructed from data.

The primary components driving the technology development are displays (primarily head-mounted and boommounted); position and orientation trackers; spatial coordinate input devices (datagloves, wand, bat or 3D mouse); directional, high fidelity audio output devices; high performance, high speed computing and accelerator boards; high resolution graphics; and physical environmental sensors.

4. Educational program at Hopkins

The mission of the Interdivisional Sensory Engineering Program (ISEP) is to facilitate the development and growth of a synthetic environments industry through basic and applied research; development of enabling technologies; education of scientists, engineers and business people; creation and support of communications channels; and fostering partnerships between academia, government, and industry.

The scientific research that defines the program is active in all of the University divisions; however, it is diverse and not focused toward the applications to synthetic environments. The ISEP is therefore organized around current activities and resources and will evolve by supplementing and augmenting existing programs.

The goals of the program are as follows:

1. Develop the infrastructure and organization: Organize the necessary resources and establish a central office for the coordination, implementation, and maintenance of the ISEP, including physical locations, laboratories and supplies, network and support, and administrative staff,

2. Establish a multidisciplinary graduate program: Organize the steering committee, design a curriculum and develop additional courses, identify and obtain funding for student support, and recruit students, to put into place the academic program in sensory engineering,

3. Seek funding for basic research: Identify and pursue contacts and sources of funding within the government and private foundations to support basic research and collaborations,

4. Seek funding for applied research projects: Identify and pursue projects and funding sources within the government to support the building of systems and virtual environment products,

5. Establish relationships with industry: Develop a plan for involving corporations and industries as partners for the development of technologies and mutually beneficial collaborations,

6. Develop professional and public relations: Develop literature and demonstrations and pursue other activities to publicize the program and the university as a center of research in the disciplines of sensory engineering.

The program consists of two parts, a sensory engineering graduate education program and a sensory engineering Technology Applications Center. These two parts provide the complementary objectives of education and research and development to define the field and set its agenda.

The graduate education program involves the academic Departments of Neuroscience, Psychology, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering, and the Part-Time Programs in Engineering and Applied Science. The program will consist of a doctoral degree in the academic departments and, eventually, a masters degree in the part-time program.

An essential component of the doctoral education will be a rotation through the various participating laboratories, within the academic departments and in the nonacademic participating divisions, such as the research laboratories at the Applied Physics Laboratory, the Center for Biomedical Visualization, the Lions Vision Research and Rehabilitation Center, and the Mind-Brain Institute. For example, students in computer science, with specific research interests in algorithms or architectures, will be able to spend six month intervals as researchers in laboratories in psychology, investigating human perception, and in the medical school, studying biological sensors. Again, in the first few years, these laboratory rotations will be organized informally within the participating divisions, and will become more formalized as the program crystallizes.

The Sensory Engineering Technology Applications Center will provide the program management and will coordinate funding and information. It will serve as the interface between the ISEP and government and industry; drive the development of the enabling technology for the sensory engineering industry; facilitate technology transfer from the University to start-up research and development and sensory engineering manufacturing companies; and collect and manage information on sensory engineering science, component technology, and applications in served industries. The components of the technology applications center include the central ISEP management, offices to broker research and development contracts and grants and to incubate programs, network management, information management, and a Corporate Council.

The Corporate Council is the vehicle for industry partnership with the University in the ISEP. It will proactively formalize collaboration between the University ISEP and business and industry. Members of the Corporate Council will pay an annual fee that will be used to support graduate students, to cover the administrative costs of the program, and to provide seed money for research projects not otherwise funded. In exchange, members will have access to technology, for potential licensing agreements, will be able to motivate the direction of the development of enabling technologies and problems for basic research, and will be provided with important and realistic information about the state of the field.

5. References

[1] Aukstakalnis, S. and Blatner, D., *Silicon Mirage*, Peachpit Press, Berkeley, California, 1992

[2] Kalawsky, R., *The Science of Virtual Reality and Virtual Environments*, Addison-Wesley, Reading, Massachusetts, 1993

[3] Sadowsky, J. and Massof, R., "Sensory Engineering: the Science of Synthetic Environments," in *Johns Hopkins University Technical Digest*, Vol. 15, No. 2, June 1994, special issue on Synthetic Environments, pp. 99-109

[4] Massof, R., Rickman, D., and Lalle, P., "Low Vision Enhancement System," in *Johns Hopkins University Technical Digest*, Vol. 15, No. 2, June 1994, special issue on Synthetic Environments, pp. 120-125

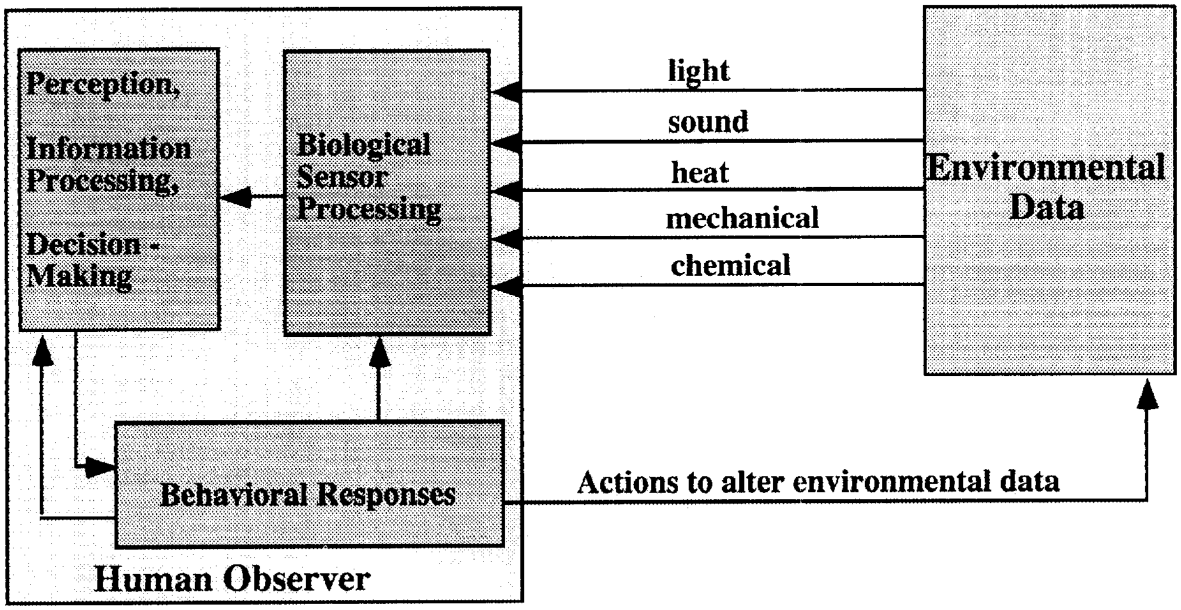

Figure 1. Simple model of a human agent interacting with the real world.

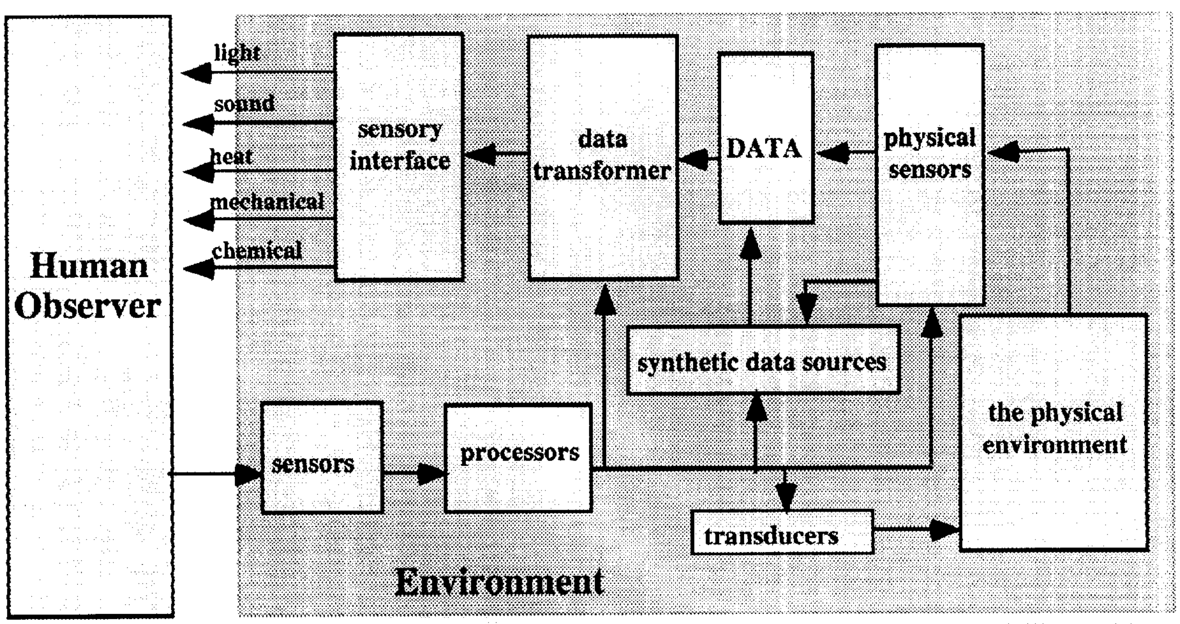

Figure 2. Enhancement and extension of the model of the human agent interacting with the real world, to include the synthetic environment. Computer-controlled interfaces replace direct interactions between the agent and the world.