NSF 99-167 PREPROPSAL**:** *ITR- RC+ HCI*

Enhancing the Quality of Life with Context-Aware Computing, Personalized Information Processing and Secure Broadband Communications: *Research at the Georgia Tech Residential Laboratory*

PROPOSAL SUMMARY

Research Objective and Expected Impact: The objective of this multi-disciplinary research program is to understand and create a class of information technologies that would enable a scientifically demonstrable enhancement of the quality of life in the home of the future. In particular, we combine *always-on broadband connectivity* with *context-aware computing* and *personalized information processing* to create new classes of capabilities ranging from crisis-avoidance and telemedicine-on-demand to novel and natural means for providing perception-of-proximity for family members and communities. An overarching goal of the proposed research is to understand the partnership between technology-centered and human-centered sciences, as technologies for sensing, computing and communications become increasingly ubiquitous. In the Georgia Tech Residential Laboratory, new sensory capabilities will be provided either in the environment or in the user's close proximity. The value of (not-necessarily-perfect) technologies will be established in carefully designed experiments resulting in both qualitative and quantitative findings. *The proposed research provides a unique opportunity for graduate students from various disciplines to work together in a truly interdisciplinary environment*

The Georgia Tech Residential Laboratory: A residential research laboratory funded by the Georgia Research Alliance has been created on campus, with state-of-the-art facilities for broadband access and computing. The laboratory has two identically outfitted levels, respectively for scientists and users, permitting an iterative approach to understanding and adapting both technology and application. The Residential Laboratory provides a natural point for synergy for the applications in the proposed research.

Context-Aware Computing: The research will identify multimodal technology that robustly locates a person , and tracks activity in the short and long term, and in relation to key objects or aspects of the residential environment. Tracking technologies include arrays of smart cameras and microphones, as well as force-sensitive smart floors---all leading to an environment that is aware of its occupants and their activities. Included in the research are networked information appliances suitable for a home setting, human-computer interaction capabilities in the form of media recognition and synthesis, used in application-specific domains, and software engineering advances that are needed for lifestyle computing.

Personalized Information Processing: Two types of wearable computers will be researched: a wearable motherboard garment with integrated optical fibers and plug-in sensors for monitoring vital medical information, and an eyeglass computer that eliminates the need of a traditional screen. As part of the research, we will provide robust wireless connectivity to the wearable computers and establish its value in combinations with traditional albeit ever-evolving technologies for personal information, such as a gigabit-wireless PDA.

Secure Broadband Wireless Communication: Emphasis in physical communications will be on last-meters technologies, particularly broadband wireless, and the use of smart antenna technology. An important research focus will be on eliminating the disconnect between indoor and pedestrian wireless, and on an integrated solution to secure wireless in-home networks. The research will also include robust communications of compressed multimedia in home networks, including joint designs of source coding, channel coding and networking.

Exemplary Applications: The research will measure human acceptance of lifestyle computing and personalized information devices. Technologies will be tested in at least three exemplary applications to lifestyle enhancement: **Telemedicine-on-demand**: We will research the use of a new wireless wearable computer (a Smart Shirt) to assist in the infant health monitoring , including the combating of SIDS (sudden infant death syndrome) and-- in later experiments-- to be part of a telemedicine experiment with older adults. The smart shirt will also be researched as a general platform for telemedicine, considering metrics of comfort, communication latency and privacy**. Aging in Place**: We will use environment- and activity-sensing technologies to make available to older adults, with the help of their remote old ones, the capability and freedom to manage themselves in their own home, while having -on-demand access to medical expertise and intervention**. Domestic Connectivity**: We will research ways of bringing family members together in increasingly rich paradigms that include peripheral and ambient communication techniques as well as virtual multimedia environments.

PROPOSAL DESCRIPTION

In describing our research, we follow the roadmap of the previous section : *context-aware computing*, *personalized information processing*, *secure broadband communications* and *exemplary applications*

1. CONTEXT-AWARE COMPUTING

The research program combines expertise in human-computer-interaction (HCI), computational perception, wearable computing, machine learning, software engineering, and cognitive aging. The Future Computing Environments (FCE) group in the Georgia Tech College of Computing has created, or is creating, several living laboratories—*Classroom 2000*, *Kids Room* , *Aware Home* and *Augmented Office*. This work has led to a much deeper understanding of the problems that face the next generation of ubiquitous computing research [Abowd,1999 and Abowd & Mynatt, 2000----See *Abowd-Bio*].

General Research Problems in Context-Aware Computing: The primary goal of research in computational perception is to develop intelligent machines, interfaces, and environments that can perceive, recognize, anticipate, and interact with humans. To this end, we are developing signal understanding and pattern recognition techniques for analyzing sensory signals from scenes and environments. We are exploring methods for perceiving where people are, recognizing them, understanding their actions, and interpreting the communicative stream. This perception can be done through an instrumentation of either the environment or the individuals in that environment. To provide an environment with such perceptual abilities requires sensors that are non-invasive and unobtrusive, so that the sensing and computing functions are transparent to the user. Our sensors include cameras, microphones, and contact sensors, such as a floor. The challenge is to leverage ever-present activity-sensing capabilities to enhance day-to-day activities [Abowd and Mynatt, 2000]. Our specific research challenges include:

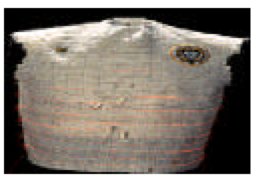
- Recognition and Interpretation of everyday activities in the home using unobtrusive technology , and
- Software Engineering to bridge activity-processing to services in computing and communications

The Smart Audio Visual Sensor* :** Arrays of cameras and microphones can track users and user activities in sophisticated and robust ways. In one experiment in event-detection, we have used analysis of video information to provide 98% accuracy in the detection of designated events such as reading, computer work, taking a phone message and accessing documents. ***The Smart Floor*:** Force-sensitive sensors located in floor tiles can identify individuals from their footfall signatures , wearing a variety of shoes. In one recent experiment with 15 subjects, the identification rate was 93%. We propose in future work to improve this number, and to solve the more difficult problem of tracking multiple subjects based on the smart floor technique. ***Software Engineering: We need novel software tools and environments that will allow designers to bridge the gap between powerful perception capabilities and useful computational services that assist everyday life. These software engineering challenges are particularly important in the development of living laboratories (Abowd, 1999). We have constructed the *Context Toolkit* (Salber, Dey & Abowd, 1999) as a first step towards bridging physical sensing and context-aware applications. ***Applications:*** Applications related to the home include: warning the individual of hazardous situations, noticing interruptions from basic tasks, and assisting in task resumption. In addition, when we focus our attention on the home, two particularly compelling applications will drive our research agenda: augmenting the home to support aging in place and in providing strong connections within the extended family (Section 4).

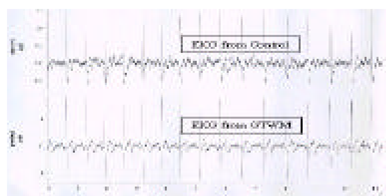
2. PERSONALIZED INFORMATION PROCESSING

Instrumentation of the individual, while potentially more invasive, facilitates capture of critical biometric information. There are two modalities for capturing personal information of various kinds: using smart sensors in the environment and using sensors close to, or on the person. The advantages of the latter approach are that it is easier to sense personal and biometric information in the proximity of the person, and that we have a better chance of controlling the dissemination and privacy of that information. The challenges, however, are that there are more information devices to coordinate and connect in the latter paradigm. Further, instrumentation of the individual is potentially more invasive, and there are human factors issues that have to do with the human's acceptance of devices close to the person. In the proposed research program, we will be investigating at least two technologies in the class of wearable computing devices, based on revolutionary uses of the eyeglass and the garment. The eyeglass device is a display in front of the pupil on the left or light lens, connected to a portable computer and simplified keyboard. The garment is a vest or shirt. In either case, the worn and carried resources augment the environmental resources discussed earlier.

Smart Shirt : The School of Textile and Fiber Engineering at Georgia Tech has created a fully woven, seamless garment that provides a versatile framework for incorporating sensing, monitoring and information processing devices [Gopalaswamy et al, 1999-- See *Jayaraman-Bio* and illustration below]. The garment uses special fibers, sensors and interconnects to monitor the vital signs of the human body. These fibers can also be used as data buses to carry information to and from plugged-in sensors and information processing devices, thus creating a motherboard. The flexible data bus transfers information to monitoring devices such as EKG machines, temperature recorders and voice recorders. The bus also serves to send information to sensors (and hence the wearer) from external sources, thus permitting two-way communications between the wearer and the outside world. The ability to sense,adapt and respond to the needs of the wearer and the environment suggests new paradigms of revolutionary computing. The wearable computer spawns a new industry for the reliable and effective monitoring of patients at home and for transforming the methodology of health care delivery, while promising other applications such as space exploration .



Georgia Tech Wearable Motherboard



EKG Traces

Wearable Motherboard on a Subject

Our proposed research in this program includes

- Better integration of the sensors into the structure in a more comfortable and form-fitting design
- Definition of technology for precise, rugged, flexible interconnections using an automated process
- Providing *wireless connectivity*, with the following features and metrics:
    - Low cost, high bandwidth, high computing speed and small device size
    - Ability to interface with existing computer hardware
    - Bi-directional multimodal multimedia communications between sensors, cameras and microphones mounted on the wearable motherboard and in remote monitoring stations
    - Portable software for decoding and displaying transmitted data, and for raising alarms as needed.

Recent work has begun to incorporate wireless connectivity into the wearable motherboard. With initial designs of data communications circuitry, and with the use of a WaveLan indoor wireless system, we have simulated the transmission of vital signals in wireless environments with signal-to-noise ratios as low as 5 dB [Firoozbakhsh et al, 2000. In review. See *Jayant-Bio*]. In future work, the wireless function needs to be transferred successively from a laptop to a palmtop and to a minimal transceiver device. We will also research real-world issues such as multi-user networks and indoor-pedestrian-outdoor survivability of the wireless signal, as well as user-friendliness of the wearable with a wireless terminal. Another key focus is the deployment of the wireless smart shirt in a realistic medical environment, considering data integrity issues-- security, privacy, latency and redundancy (Section 4).

The Gigabit Wireless PDA: The least invasive kind of personal information technology is a personal digital assistant. As part of a State of Georgia initiative in Broadband Telecommunications, we are developing a voice-agile internet interface with gigabit wireless connectivity. In this two-way system, the mobile user accesses the Web using automatic speech recognition, and system feedback to the user is based on text-to-speech synthesis. In the proposed research, we will investigate the enhancement of this information device using complementary uses of the audio and visual dimensions in the user interface.

3. SECURE BROADBAND WIRELESS COMMUNICATIONS

A central aspect of the communications revolution is the upgrading of access to homes and communities to broadband capability. Broadband alternatives include cable, DSL, wireless, satellite and optical access.

Of particular importance is the use of wireless for the so-called last mile solutions , especially in rural segments of the population. Also central is the issue of wireless networking within the home, regardless of the physical mode of broadband access to the home or its neighborhood.

More and more of us are using wireless devices because of their convenience. However, that convenience is also extended to those who would do us harm. By putting our waves on the air, we make our information, and therefore ourselves, vulnerable to various interceptors: pranksters with Radio Shack parts, identity thieves who would destroy our credit ratings, and paid assassins with the very latest technology.

Research planned around the Residential laboratory includes the identification and investigation of security flaws in home and personal wireless systems, as well as constructive enhancements in security provisioning . This includes *detection of intrusions, prevention of signal interception and maximization of privacy,* based on:

- selection and design of building materials
- positioning of wireless equipment and devices in, around and outside the home
- *smart antenna technology based on propagation studies and advanced signal processing*

Smart Antennas: Array antennas will become more prevalent in wireless appliances because the technology is growing more economical and because they yield better performance and more functionality than conventional omni or directional antennas [Li and Ingram,1998 and Zhou, Ingram and Anderson,1998-- See *Ingram-Bio*]. Array antennas, when used in short-range, low-power wireless systems in the home, will change the characteristics of the signal that leaks out of the house. For example, base units with electronically steered beams in a time-slotted protocol selectively excite different direct and reflected or diffracted paths of propagation at different points in time, whereas conventional antennas excite all paths all of the time. Wireless base units that use transmission diversity to lower the cost of handsets also provide diversity to the undesired receivers, possibly easing their job of interception. In the proposed research, we will determine the "hear-ability" of wireless emissions from the home through measurements and theory, and study the value of shielding, antijam processing and beamforming methods. Metrics will include the probability of interception as a function of range, receiver sensitivity, type of home construction, and location of the indoor emitter.

The flexibility and extra degrees of freedom offered by array antennas also gives system designers new capabilities for wireless security. For example, while electrical shielding is one way to protect indoor wireless systems, there will always be places where signals can leak out or leak in, for example, through exterior doors. We will investigate ways that an array antenna can minimize the power of signals exiting the house as well as masking signals that do exit the house. We will seek to develop novel techniques that combine spatial and temporal signal processing as well as consider the application of traditional electronic countermeasure techniques that have been developed for array radar. As an example, we could assume that the indoor transmitter knows the complete channel descriptions for a collection of undesired outdoor receiver locations as well as the channel descriptions to various desired receiver locations within and near the home. Under those conditions, one possible strategy is to identify the signal subspace that best spans the collection of indoor-to-outdoor signatures, and transmit only signals that are orthogonal or nearly orthogonal to that subspace. We will also investigate strategies that assume that the transmitter has partial or no information about the channel.

We propose measurements that will capture various levels of interception sophistication as well as various levels of transmitter sophistication. For interception, we propose to acquire the leaking signals using simple narrowband techniques as well as a digital 8-channel array receiver. We can then simulate the interception performance of a receiver with as few as one and as many as eight receive channels. To test our space-time transmission techniques, we propose to characterize the multipath propagation channel from indoor-to-the-curb using a wideband array-to-array channel sounder. These measurements, which capture angles-of-departure, angles-of-arrival, polarization, phase and delay of all propagation paths, will afford us the flexibility to test algorithms offline under various assumptions of transmitter and receiver complexity.

Key research Issues: Minimizing the vulnerability of a home wireless network that supports lifestyle computing.

4. APPLICATIONS

The technologies of Sections 1 to 3 will be used in many combinations to enable the applications that are an integral part of the proposed research. These applications have common research threads: understanding the application of technology, understanding the value of technology parameters such as bandwidth in access and the recognition accuracy in HCI, and using the human-centered results to create new technology and science. We will address both short-term and long-term applications of Information Technology in the home. Information management systems are a good class of near-term application. Realizing an always-connected lifestyle using the full promise of communications, computing and multimedia is a long-term challenge, with *technical***,** *cognitive* and *societal* dimensions that we will concurrently address.

4.1 Telemedicine for Infants and Older Adults--The Wireless Smart Shirt Project: Experiments with the smart shirt will address preventive as well as rehabilitative applications. Respective examples include proactive maintenance of medicinal regimen and post-accident attention, using low-latency monitoring of smart shirt data. Proposed research on wireless security will apply naturally to these applications. The smart-shirt technology will be useful in monitoring patients in post-operative recovery, geriatric patients (especially those in remote areas), mentally ill or depressed patients, infants susceptible to SIDS (sudden infant death syndrome), and individuals prone to allergic reactions. In the initial phase of the proposed research, we will work with pediatricians at the Emory School of Medicine to test the Smart Shirt on babies. Simultaneously, we will be refining the design of the garment and its wireless connectivity. In a second phase of our research, we will use the wireless smart shirt in the Residential Laboratory with older adults, to co-define with them useful forms of telemedicine.

***Key Research Issues*:** Common to both of the above applications and research phases are the metrics of data integrity, latency, redundancy, privacy, immediacy, and human acceptance of the wearable.

4.2 Aging in Place: America’s population is aging. According to the U.S. Census Bureau, in 1996 there were approximately 550 million adults over age 60 and this number is expected to approach 1.2 billion by the year 2025. In the U.S. alone, there were nearly 44 million adults over age 60 in 1996. The projected number for 2025 is approximately 82 million (over 20% of the total population). Baby boomers approaching late middle age ask: “How does one care for a population that lives many years longer than any of the preceding generations?” Most older adults live in independent households; it has been estimated that only 5% of the older population reside in nursing homes . However, this number does increase with age, and 20% of individuals over age 80 live in nursing homes.

For economic reasons alone, increasing the length of time that individuals can avoid nursing home care is valuable. In addition, a primary goal of many older individuals is to maintain or enhance quality of life through an independent lifestyle. According to the Administration on Aging (1997), there are many factors that contribute to the independence of older individuals:marital status, living arrangements (alone or with others), household status (head of household or not), education, economic dependency, and income. A variable that has not been studied is the degree to which the house itself is supportive of the functioning of the individual.

The field of cognitive aging has made a lot of progress in understanding the basic cognitive changes that accompany the normal aging process. Some abilities do decline, yet other abilities remain intact well into the seventh or eighth decade of life. Of course there are substantial individual differences in the rate of decline and the amount of decline. However, in general, personal abilities ---aspects of memory such as keeping a lot of information active in working memory), online reasoning ability, and aspects of attention such as attending to more than one source of information --- all show age-related declines. On the positive side, abilities that tend to remain intact into old age include some aspects of memory (e.g., recalling well-learned information), verbal abilities such as vocabulary and reading, and some aspect of attention (e.g., focusing on a single source of information). Designers must recognize and accommodate those abilities that do decline while at the same time capitalize on the abilities that remain intact.

Key Research Issues: Use of perception, software engineering and communications for natural monitoring of lifestyle , with close attention to the needs , desires and abilities of older adults.

4.3 Domestic Connection: In many situations, particularly in the domestic domain, the so-called "connecting" technologies of car , airplane and phone are poor substitutes for being nearby . We need ways for the family members to connect in a more continuous fashion. We need more light-weight technologies for connecting (perhaps in the spirit of email). Some of these technologies , such as virtual multimedia environments, can be bandwidth-demanding. Some others may be low-bandwidth means, using more peripheral and ambient displays such as a picture from a family that communicates information about family activities on an on-going basis, to create an illusion of being there.

Most technological advances in the 20th century have resulted in the American family being more physically distributed. A negative result of this is the disintegration of family connections. One hope for technology of the 21st century is that it will reverse this negative trend. How can we use computational resources to promote a feeling of physical proximity that might lead to a feeling of social and emotional proximity? When address aging in place, it may be just as important to give children a feeling of connection to their aging parents as it is to enable a house to support the independence of the aging parent. Grandparents desire to know what their grandchildren are doing. How can we give them the feeling that they live next door to their grandchildren through multimodal communications channels? We have initiated studies into how ambient visual displays can provide aesthetic cues between remote family members. We have also investigated how audio signals can be used as ambient cues in the office place to increase awareness of group activities.

The capability that we are interested in goes well beyond sophisticated video teleconferencing, which is rather intrusive and expensive. We are aiming for collections of less intrusive and more peripheral modes of communication. For example, when a grandmother lives next door to her grandchildren, she can hear them playing in the backyard. How can this same awareness of activity be handled when the households are separated by an entire continent? As another example, consider childcare arrangements for dual-income households. When a child spends many hours at a separate daycare facility, the parents have relatively little interaction. Some families choose to have live-in nannies and have one or both parents working at home in a home-office. In the latter situation, the parent has easy access to information about the children while still being able to work productively. How can we support the former daycare scenario while still maximizing the awareness between parent and child?

Key Research Issues: use of peripheral communications and virtual multimedia environments to provide compelling and demonstrably useful connections and perceptions-of-proximity for:

- aging parents and their children
- working parents and their children in daycare
- communities and families in general

5. THE RESEARCH TEAM

Principal Investigators [all from the Georgia Institute of Technology]:

Dr Nikil Jayant	School of Electrical and Computer Engineering
Dr Gregory Abowd	College of Computing
Dr Sundaresan Jayaraman	School of Textile and Fiber Engineering
Dr MaryAnn Ingram	School of Electrical and Computer Engineering

Other Senior Personnel from Georgia Tech [from the Colleges of Engineering, Science and Computing, and from the Georgia Tech Research Institute]:
Dr Blaine Burnham, Dr Blair McIntyre, Dr Irfan Essa, Dr Chris Atkeson, Dr Thad Starner, Dr Aaron Bobick , Dr Beth Mynatt , Dr Phyllis Schneck , Dr. Wendy Rogers , Dr Mark Clements, Dr Monson Hayes and Mr Andy Quay
Senior Personnel Outside of Georgia Tech:
Collaborator in Telemedicine (Pediatrician from Emory University School of Medicine)
Collaborator in Consumer Factors (University of Georgia)

Research Engineers (2)