LiveNet: Health and Lifestyle Networking Through Distributed Mobile Devices

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ABSTRACT

Incorporating new healthcare technologies for proactive health and elder care will become a major priority over the next decade, as medical care systems world-wide become strained by the aging boomer population. We present MIThril LiveNet, a flexible distributed mobile platform that can be deployed for a variety of proactive healthcare applications. The LiveNet system allows people to receive real-time feedback from their continuously monitored and analyzed health state, as well as communicate health information with care-givers and other members of an individual's social network for support and interaction.

1. INTRODUCTION

The United State's dramatically aging population --- 76 million baby boomers reaching retirement age within the next decade --- will require great changes to the existing medical care system. The U.S. healthcare system is not structured to be able to adequately service the rising healthcare needs of the aging population, and a major crisis is imminent. Under the current system, a patient visits the doctor only once a year or so, or when they already have clear symptoms of an illness. The failure to do more frequent and regular health monitoring is particularly problematic for the elderly as they have more medical issues and can have rapidly changing health states. Even more troubling is the fact that current medical specialists can't explain how most problems develop, because they usually only see patients when something has already gone wrong.

The best solution to these problems lies in more proactive healthcare technologies that put more control into the hands of the people. The vision is a healthcare system that will help an individual to maintain their normal health profile by providing better monitoring and feedback, so that the earliest signs of disease can be detected and corrected. This can be accomplished by continuously monitoring a wide range of vital signs, providing early warning systems for people with high-risk medical problems, and "elder care" monitoring systems that will help keep seniors out of nursing homes.

There has been a dichotomy in the mindsets of researchers as to the best methodology for implementing these future healthcare applications. One philosophy focuses on putting sensing and technology infrastructure in the environment, freeing the individual from having to carry anything. Pervasive computing, ambient intelligence, and 'smart rooms' all fit into this paradigm. While this methodology is attractive as it makes the technology transparent, it has potential downsides from large implementation costs as well as the fact that the technology is limited to being effective only where the infrastructure exists. Furthermore, it is often not technically feasible or practical to be able to obtain some types of information from sensing at a distance (such as physiological information).

At the other end of the spectrum, the wearable computing community has focused on developing mobile health technology that people can carry at all times, wherever they go. While this provides the opportunity to be able to constantly and intimately monitor all the relevant contextual information of an individual as well as providing instantaneous feedback and interaction, it comes at the cost of potentially being invasive, unwieldy, and distracting.

There exist rich opportunities that lie somewhere in between these two polar methodologies. By combining elements from each type of technology, it is possible to leverage the benefits of both to create a system that is more flexible than either alone. LiveNet attempts to do this, creating a powerful mobile system capable of significant local sensing, real-time processing, distributed data streaming, and interaction, while relying on off-body resources for wireless infrastructure, long-term data logging and storage, visualization/display, complex sensing, and more computation-intensive processing.

2. THE MITHRIL LIVENET SYSTEM

The LiveNet system is based on the MIThril 2003 architecture, a proven accessible architecture that combines inexpensive commodity hardware, a flexible sensor/peripheral interconnection bus, and a powerful light-weight distributed sensing, classification, and inter-process communications software layer to facilitate the development of distributed real-time multimodal and context-aware applications.

There are three major components to the MIThril LiveNet architecture; a PDA-centric mobile wearable platform, the Enchantment software network and resource discovery API, and the MIThril real-time machine learning inference infrastructure. Each of these components are briefly described below. For a more detailed description of the hardware and software infrastructure used by LiveNet, please reference [1].

2.1 Hardware and Sensing Technology

The MIThril LiveNet system is based on the Zaurus SL-5500, a linux-based PDA mobile device. This system allows applications requiring real-time data analysis, peer-to-peer wireless networking, full-duplex audio, local data storage, graphical interaction, and keyboard/touchscreen input.

A sensor hub, which can also function independently as a compact flash based data acquisition platform, is used to interface the PDA with the sensor network. A small sample of implementations of the sensor hub in stand-alone operation include real-time critical health monitoring [2] and identifying activities of daily living [3], and social network monitoring.

Currently available stand-alone sensor designs include accelerometers, IR active tag readers (used in conjunction with IR tags that can be used to tag locations or objects), battery monitors, GPS units, microphones, EKG/EMG, galvanic skin response (GSR), and temperature sensors. The sensor hub also allows us to interface with a wide range of commercially available sensors, including pulse oximetry, respiration, blood pressure, EEG, blood sugar, humidity, core temperature, heat flux, and CO_2 sensors. Any number of these sensors can be combined through junctions to create a diversified on-body sensor network.

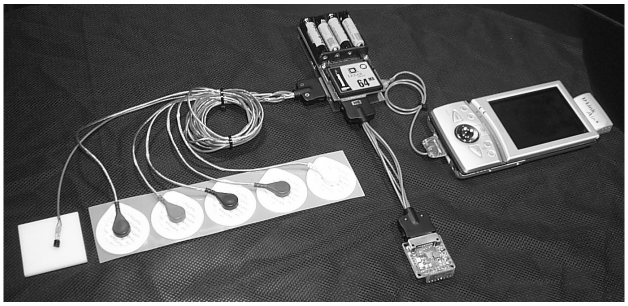

Figure 1: MIThril system, composed of the Zaurus PDA (right) with Hoarder sensor hub and physiological sensing board (top), EKG/EMG/GSR/ temperature electrodes and sensors (left) and combined three-axis accelerometer and IR tag reader (bottom)

2.2 Software Infrastructure

The Enchantment API is an implementation of a whiteboard inter-process communications and streaming data system suitable for distributed, light-weight embedded applications. It provides a uniform structure and systematic organization for the exchange of information that does not require synchronous communications. Enchantment is intended to act as a streaming database, capturing the current state of a system (or person, or group) and can support many simultaneous clients distributed across a network and hundreds of updates a second on modest embedded hardware. We have even demonstrated the ability to use the Enchantment for bandwidth-intensive VoIP-style audio communications.

2.3 Context Classification System

The MIThril Inference Engine is a simple, clean architecture for applying statistical machine learning techniques to the modeling and classification of body-worn sensor data. The important design features of the system are simplicity, modularity, flexibility, and implementability under tight resource constraints. The Inference Engine abstracts the data analysis into distinct steps, including the transformation of raw sensor data into features more suitable for the particular modeling task, the implementation of statistical and hierarchical, time-dependent models that can be used to classify a feature signal in real time, and the development of Bayesian inference systems which can use the model outputs for complex interpretation and decision-making.

3. APPLICATIONS

Most commercial mobile healthcare platforms have focused on data acquisition applications to date, with little attention paid to enabling real-time, context-aware applications. Companies like Digital Angel, Lifeshirt, Bodymedia have extended the basic concept of the ambulatory Holter monitor (enabling a physician to record a patient's EKG for a small continuous period of time), which for decades was really the only common health monitor in existence.

In contrast, we are building a multi-functional mobile healthcare device that is at the same time a personal health monitor, social network support enabler and communicator, context-aware agent, and multimodal feedback interface. A number of key attributes of the LiveNet System that make it an enabling distributed healthcare system include:

- Wireless capability with resource posting/discovery and data streaming to distributed endpoints
- Flexible sensing for context-aware applications that can facilitate interaction in a meaningful manner and provide relevant and timely feedback/information
- Unobtrusive, minimally invasive, and non-distracting
- Continuous long-term monitoring capable of storing a wide range of physiology as well as contextual information
- Real-time classification/analysis and feedback of data that can promote and enforce compliance with healthy behavior
- Trending/analysis to characterize long-term behavioral trends of repeating patterns of behavior and subtle physiological cues, as well as to flag deviations from normal behavior
- Enables new forms of social interaction and communication for community-based support by peers and establishing stronger social ties within family groups

In remainder of this section, we present a variety of real-world and potential applications of the MIThril LiveNet System.

3.1 Health and Clinical Classification

The LiveNet system has proven to be a convenient, adaptable platform for developing real-time monitoring and classification systems using a variety of sensor data, including accelerometer-based activity-state classification (that can differentiate between activities such as running, walking, standing, biking, climbing stairs, etc.) [4], GSR-based stress detectors, accelerometer-based head-nodding/shaking agreement classifiers, and audio-based speaking state (talking/not talking, prosidy) classifiers which can help characterize conversation dynamics [5].

Work on these real-time classifiers has also been extended to include critical health conditions. Examples of current collaborations between the Human Dynamics Group and clinicians include a study on the effects of medication on the dyskinesia state of Parkinson's patients with a Harvard neurologist [6], a pilot epilepsy classifier study with the University of Rochester Center for Future Health, a depression medication study with the MGH Department of Neuroscience, and a hypothermia study with the ARIEM (Advanced Research in Environmental Medicine) at the Natick Army Labs [7].

The sensor data and real-time classification results from a LiveNet system can also be streamed to off-body servers for subsequent processing, trigger alarms or notify family members and caregivers, or displayed/processed by other LiveNet systems or computers connected to the data streams for complex real-time interactions.

Figure 2: MIThril LiveNet wearable performing real-time FFT analysis and activity classification on accelerometer data, visualizing the results, as well as wirelessly streaming real-time EKG/GSR/temperature and classification results to a remote computer with a projection display as well as peer LiveNet systems that may be anywhere in the world.

3.2 Long-term Health/Behavioral Trending

The MIThril LiveNet platform also lends itself naturally to be able to do a wide variety of long-term healthcare monitoring applications by using the currently available physiological sensors. The atomic classifiers discussed in Section 3.1 can be combined together in a hierarchical manner to develop time-dependent models of human behavior at longer timescales.

We are collaborating on the MIT/TIAX PlaceLab, a cross-institutional research smart living environment [8], to provide a very robust infrastructure to be able to collect and study long-term health information in conjunction with data collected by LiveNet systems.

The information collected from the multimodal sensors can then be used to construct activities of daily living, important information in being able to profile a person's healthy living style. Furthermore, these activities of daily living can initiate action on the part of the wearable PDA. Examples include experience sampling, a technique to gather information on daily activity by point of querying (which can be set to trigger based on movement or other sensed context by the PDA). The system can also proactively suggest alternative healthy actions at the moment of decision, where it has been demonstrated as being more effective at eliciting healthy behavior [9].

3.4 Community Support and Feedback

Traditionally, mobile healthcare applications are usually thought of in the context of single users, such as individualized monitoring, bio-feedback, and assistive PIM applications. LiveNet allows us to extend this paradigm by using mobile technology to also assist and augment group collaboration and other types of social interaction.

One of the main problems with new health technology, particularly for the technophobic elderly, is that it can be very impersonal and distracting. As such, compliance has always been one of the largest problems of using information technologies within the healthcare industry.

Social groups activities provide a compelling way to support and enforce compliance, potentially eliciting healthy behavior in peer groups. One example of this is DiaBetNet [10], a distributed PDA-based handheld game that has been shown to help diabetic children learn to regulate their own blood sugar levels through competitive community games.

The LiveNet systems can also be configured to enable point-to-point real-time audio data streams, functioning as communicators that can provide instantaneous voice interaction to groups. By simply pushing a button, individuals can communicate with each other without effort, thereby strengthening the social network and peer support groups. Reducing the effort needed to communicate can significantly change group interaction dynamics, much as instant messaging revolutionized text communication relative to slower email communication. Through these instantaneous communication channels, it is possible to create the feeling of virtual proximity of social peer or family groups, despite the fact that there may be large geographical separation between individuals.

4. CONCLUSIONS

The MIThril LiveNet system embodies a flexible system infrastructure capable of a variety of individual and group-based context-aware healthcare applications. As the various applications demonstrate, there is great promise for this system to be able to allow groups of individuals to communicate and support each other more effectively.

5. REFERENCES

[1] R. DeVaul, M. Sung, J. Gips, and A. S. Pentland, "MIThril 2003: Applications and Architecture", International Symposium of Wearable Computers, October, 2003

[2] M. Sung, VitaMon: Critical Health Monitoring, http://www.media.mit.edu/~msung/vitamon.html, 2002

[3] House_n MIT Home of the Futue Consortium, http://architecture.mit.edu/house_n/

[4] R. W. DeVaul and S. Pentland. "The MIThril Real-Time Context Engine and Activity Classification", Technical Report, MIT Media Lab, 2003.

[5] N. Eagle, A. Pentland, "Social Network Computing", Conference on Ubiquitous Computing (UbiComp), 2003

[6] J. Weaver, "A Wearable Health Monitor to Aid Parkinson Disease Treatment", MIT M.S. Thesis, June 2003.

[7] M. Sung, "Shivering Motion/Hypothermia Classification for Wearable Soldier Health Monitoring Systems," Technical Report, MIT Media Lab, Dec. 2003

[8] MIT/TIAX PlaceLab, http://architecture.mit.edu/house_n/web/placelab/PlaceLab.pdf

[9] S. Intille, C. Kukla, and X. Ma, "Eliciting User Preferences Using Image-Based Experience Sampling and Reflection", Conference on Human Factors and Computing Systems, April 2002

[10] V. Kumar, A. Pentland, "DiaBetNet: Learning and Predicting for Better Health and Compliance", Diabeties Technology Society meeting, Foster City, CA Oct 31-Nov 2