Health-OS: A Position Paper

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ABSTRACT

The area of medical monitoring and diagnostics is of particular importance and relevance today. Modern nanotechnology has reduced prices and size of increasingly sophisticated sensors. Short-range wireless communication has become advanced enough to support inexpensive active sensor systems. Wearable computing devices are ubiquitous and increasingly powerful. As a result of these advances, a growing number of health monitoring systems with increasingly sophisticated capabilities are available today. Moreover, there is growing public interest in products that allow individuals (from children to elders) to monitor and improve their own health. These trends create an increasing demand for platforms that aim to support and improve one's health and lifestyle.

We propose Health-OS, a middleware platform for multi-device sensing that transparently monitors, stores, transmits, analyzes and presents various physiologically based signals. The objective is to unify an open group of sensing mechanisms with a myriad of computing platforms and applications via a common platform equipped with a software development kit.

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General Terms: Design, Standardization, Management, Human Factors

Keywords: Health, Operating Systems, Middleware

1. INTRODUCTION

Because of the high value we put on our quality of life in the Western world, health care is a crucial institution that exists within society today. In fact, according to the US Census Bureau, US health care was a $1,280B industry for 2003[1], and professional-only medical diagnostics, home health-care, and social assistance revenues generated $30B, $36B, and $94B, respectively. One of the key trends in the industry is a persistent infiltration of computational and sensing technologies in most of its areas. For example, medical care has traditionally been performed in clinics by professionals who would acquire snapshots of the patient's medical lives at fairly discrete periods in time. It is not uncommon that such sporadic doctor's visits do not allow doctors to catch all health-related problems in a timely fashion. Recently, the health care industry has been undergoing a substantial paradigm shift that allows patients to take more active roles in taking care of their health.

Technological trends and societal patterns point to the growing demand for health-improvement and biofeedback products. We speculate that devices that address important issues such as stress monitoring, preventive care, chronic disease management, productivity and ergonomics, assisted living, telemonitoring of basic physiology in remote locations, athletic conditioning, and biofeedback-based entertainment, will be in strong demand.

In this paper, we propose Health-OS, a middleware platform that enables multi-device sensing, as well as near-transparent monitoring, analysis, storage, transmission and presentation of physiologically and environmentally based signals.

2. RELATED WORK

In recent years there has been increasing interest in the areas of distributed medical monitoring and diagnostics (which divides responsibility between the patient and the doctor), at-home health monitoring and wearable or environmentally embedded (ubiquitous) technology to help patients monitor their health. Within these efforts, there exists a fairly large body of work aimed not only at improving biosensor technology, but also at packaging the sensors into integrated systems that provide automated healthcare delivery in various environments. Finally, there is a growing body of work in the areas of data mining and presentation of health-related information.

2.1. Sports Monitoring

Using wearable sensors to monitor and analyze physiological data while exercising seems to be a popular, attractive, and profitable domain. There are today sophisticated watches [4], helmets [5] and mobile phone applications [9] that assist users in their exercise routine and goals.

2.2. Wearable Health Monitoring

Wearable physiological sensor systems have also been used for more general health monitoring. Most of the systems allow users to monitor various physiological signals while at home. They typically send the data wirelessly to a local or remote base station for processing and display [14, 15, 6, 13].

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In addition, a small number of more sophisticated systems perform real-time analysis of the signals [8].

2.3. At-Home Health Monitoring

The concept of a smart home, *i.e.* a home instrumented with sensors that are able to constantly monitor the daily activities of its inhabitants, has received particular attention and research interest in recent years [7, 10, 11, 12].

We believe, however, that there exists a notable gap in work aimed at developing a unified platform on which such technologies can operate. In most work to date, researchers have developed fairly closed systems, making it difficult to integrate new sensors, or more importantly to achieve interoperability of heterogeneous medical and environmental sensors. The platform proposed in this paper aims at filling this gap by addressing challenging issues such as sensor transparency and interoperability, energy consumption and power harvesting, user interfaces and data visualization, signal processing, communications, and privacy.

3. HEALTH-OS

We envision Health-OS as a unified platform for sensing environmental and physiological signals continuously. Health-OS manages, stores, and analyzes the sensed data, and presents it to the user or forwards it to a health-care professional. Figure 1 depicts an example of how Health-OS would facilitate implementing end-to-end sensor-based biofeedback applications. At the lowest layer, Health-OS provides a seamless interface for connecting any physiological or environmental sensor to a mobile computer or server. Health-OS contains a collection of libraries with their corresponding APIs for data acquisition and transmission, feature extraction and analysis, data storage, compression and visualization, etc. We expect developers to leverage the functionality of the Health-OS software development kit (SDK) for building innovative applications in three major domains: consumer, health professional, and research markets.

3.1 Architecture

As illustrated in Figure 1, the Health-OS platform consists of three distinct components: a sensing module, a mobile personal data hub, and a trusted personal computer. The key to the modularity and efficacy of the system is task partitioning.

The goal of the sensing module is to provide Health-OS with access to the external world. The sensors should operate near-transparently to the user's daily activities – hence, we assume that they are embedded in the user's clothing, shoes, furniture, etc. Each sensing module encapsulates: sensor and A/D conversion circuitry (if required), a controller for data modeling, compression, and analysis, a communications module with encryption and error correction codebooks, memory, and an energy source. Given a hard or soft real-time schedule of tasks that may be derived based on the model of the sensed signal, the goal of the system designer is to partition the computation involved in delivering the sensed signal to the personal data hub with minimal overall power-consumption. Some of the greatest challenges lie in delivering power to the sensors via innovative ways for energy harvesting via piezoelectric [16], induction-based [17], or other forms of power. In addition, technologies such as energy-aware e-textiles [18] can provide substantial energy savings over wireless transceivers.

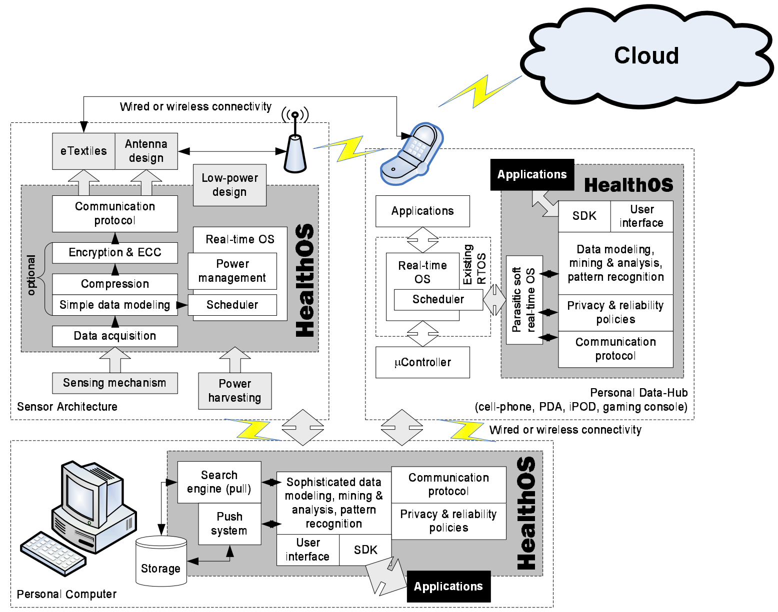

Figure 1: Schematic representing the Health-OS framework across several computing platforms.

The sensed data, possibly compressed, is sent to a personal data hub, a central computing unit responsible for storing and analyzing the data collected from the sensors. This personal data hub is also wirelessly connected to a communications network and therefore can upload the data to the network "cloud" or a remote server. Its simple user interface would be sufficient to provide the user with the necessary information. Energy efficiency is a key factor in the portable sensor and data hub design. The data hub could be a dedicated device or be integrated into a product users already carry with them such as a cell-phone, PDA, or a portable entertainment center. The data hub would synchronize its contents relatively infrequently with a personal computer (PC) trusted by the user. At that time, the hub would upload its stored data as well as any other associated information to the PC. The PC could perform more sophisticated tasks such as data modeling and analysis, sensor signal fusion, signal-specific lookups into off- and on-line medical libraries, data transmission, etc. The design of sensing modules as well as the data hub poses several important challenges.

The design of the personal data hub would depend on whether the data hub is dedicated or Health-OS functionalities are incorporated into an existing mobile device. In the latter case, Health-OS is likely to behave as a parasitic real-time operating system (RTOS) with respect to its applications – hence, it must resolve its real-time calls via the host RTOS and its scheduler providing required quality of service – an objective which has not been addressed yet to the best of our knowledge. Assuming that the personal hub is capable of predicting the responses of the attached sensors, signal processing routines can be used as guidelines for Health-OS'es parasitic scheduler.

3.2 Key Properties

In light of the applications that would be built on top of

Health-OS, the system requires an inherent list of desiderata:

1. Near-Transparency. Physiological sensors are typically distinguished by various degrees of intrusiveness, where intrusion may involve using body tissue to diagnose a particular physiological state or condition. However, so called non-intrusive sensors are typically obtrusive and cumbersome. Health-OS sensors should be *transparent* or near-transparent, *i.e.*, they would continuously obtain biofeedback from the user's body, with little or no additional action taken by the users compared to their usual daily routine. Transparency is key to adoption by most users – sensors built as armbands, chestbelts, etc. are typically met with resistance among many users. To achieve real pervasiveness, sensors should be integrated near-transparently with the users routines and living environment, including their garment, shoes, accessories, cars, furniture, etc. Needless to say, sensors should also be "transparent" to the user's health – they should not cause allergic responses or induce undesirable health conditions. Fortunately, advances in MEMS, nanotechnology and biosensors will provide more non-intrusive sensing capabilities.

2. Favorable Accuracy and Reliability vs. Cost of Operation. A Health-OS application would obtain high-accuracy and reliability data using relatively inexpensive sensors. Although most labs-on-chip are on-par with precise laboratory tests, it still should not be expected from Health-OS to provide professional-grade accurate, reliable, and timely results. The emphasis is on monitoring, not on diagnosing, with a similar liability model than that of companies manufacturing non-medical physiological sensing devices.

3. Secure Communication. It is expected that users choose to have their desired level of privacy in parts of or in all collected data with respect to access by relatives and friends, health insurance providers, and health-care professionals. Health-OS would include standards that enable and handle privacy far more efficiently than separate systems. The cryptographic routines to fully enable privacy are well understood and documented in standards [2] and usability studies [3].

4. Analysis. Health-OS does not target professional medical diagnosis nor aims at making decisions related to one's health – both actions are usually delegated to human expertise. It is meant to be used as a system that records and digests the history of one's physiology and activity level with high accuracy and reliability. Health-OS analyzes the sensed data with different levels of abstraction and detail, in order to present it to a laïc as well as a health-care professional in a compact format. Applications built on top of Health-OS analysis tools include: (1) health-based recommendation systems that would suggest users, for example, to get a check-up or undergo some lifestyle changes (*e.g.* ergonomic, activity-level, nutrition, or stress-related); (2) medication compliance reminder systems; (3) entertainment systems and (4) user education.

The primary role of Health-OS analysis tools in the medical community would be as a provider of a continuum of data beyond the sporadic data point a doctor normally obtains today, and as a research tool.

5. 4As. This concept, borrowed from the ubiquitous computing research community, relates to "anywhere, anytime, anyone, any device." In the context of Health-OS, the system should make the recorded data and its analysis available to the user or health-care professional in a 4A-style, according to user-specified privacy scenarios. Users may choose to store all or parts of the data on their PCs, health insurer's network, independent on-line repository, smartcard, or even a portable "healthPOD."

4. SUMMARY

Fueled by advances in technologies and societal needs, we now have the unprecedented potential to provide continuous physiological-monitoring to individuals as they go about their everyday lives. In this paper, we have proposed Health-OS, a middleware platform that enables multi-device sensing, and transparent monitoring, analysis, storage and presentation of a number of physiological signals. The objective is to unify an open group of sensing mechanisms with a myriad of computing platforms and applications via a common platform equipped with a software development kit. Health-OS enables easy and fast development of a wide range of physiology-based applications, setting the path for the upcoming revolution in health and wellness.

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