Integration of Heterogeneous Motion Sensors and GPS in Healthcare Oriented Body Sensor Networks

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Abstract— In this paper, we propose and implement a mobile Body Sensor Network (BSN) that integrates a mobile device with wireless motion sensors and a positioning sensor such as GPS. This network significantly improves mobility by connecting the base-station to a mobile device carried by the user, whereas traditional BSN systems rely on using stationary base-stations that inherently limit the user's distance and functionality. The motion sensors worn on the body transmit data to the base-station, which supports persistent monitoring of human activities in both indoor and outdoor environments. In addition, we further provide the location information of the activities with the integration of GPS. We demonstrate the relevance of this system in healthcare-oriented applications. We particularly show that the system enhances the ability to monitor movements and their positions. Furthermore, it makes room for new functionalities such as air particle sensors to detect airborne particle matter (air pollution) encountered on a daily route. This work opens up an array of possibilities to the revolutionary alliance between BSNs and the healthcare industry.

I. Introduction

As our technological capabilities mature, our ability to enhance many applications greatly expands. Among this development is the need to further advance healthcare applications. The focus of Body Sensor Networks is to develop a system for quantitative measurement and assessment of motor function in children and adults. Quantitative measurements of motor function will allow for more complete, reliable and interpretable assessments of function for individual subjects.

Locomotion monitoring is the study of the biomechanics involved in human locomotion and gait development. This study is useful in gait analysis, early diagnosis of cognitive impairments like dementia and Alzheimer's, detection of autistic disorders in infants, etc. Additionally, the study of gait development and cognitive abilities in children indicates that various developmental disorders may be marked by differences in gait or motor development.

Interlacing mobile and GPS devices in Body Sensor Networks will increase independence, and provide convenient use and smart execution. This system ensures that these applications are non-prohibitive and available to all patients. Portability broadens physical movement, which further increases the accuracy of not only the data, but also of one's lifestyle. It is important that location restrictions and/or physical restraints are limited. An imperative objective of the entire system is to allow for the smoothest transition into healthcare monitoring while ensuing as little conspicuous change as possible.

GPS location data can greatly augment our understanding of locomotion and its impairments. Combined in a mobile system, we can use the GPS location data to potentially identify those environments in which locomotion is impaired (e.g., steep terrains, absence of sidewalks, damaged or uneven walkways). This may aid potential planning and policy objectives for improving accessibility to individuals with locomotion difficulties. Moreover the GPS location data combined with the BSN data may help us identify where accidental falls occur, and when they do occur, potentially notify emergency personnel where to go to rescue the user.

There is also great potential for the integrated monitoring of other environmental factors besides GPS location that may help us understand possible factors that might relate to locomotion and its impediments. For example, in this study we evaluated the user's exposure to airborne particle matter (PM). PM is not a gas or specific chemical, but rather a complex mixture of small dry solid material and liquid droplets in the air that we breathe into our lungs. Of special concern is particle matter that comes from diesel exhaust, exposure to which has been shown to be associated with cancer[i]. Particulate matter can come from other sources besides diesel exhaust, including the burning of other fuels, such as gasoline and wood. Fine particles that are 2.5 microns or smaller in diameter are referred to as $PM_{2.5}$. These small sizes are of concern because they penetrate deep into the lungs, thereby increasing the risk for health effects. $PM_{2.5}$ exposure has been associated with a broad range of health effects, including premature mortality[ii]. The California annual air quality standard for outdoor $PM_{2.5}$ is set at 12 micrograms per cubic meter (0.012 mg/m^3), averaged over the year. In California, a new 24-hour-average standard for $PM_{2.5}$ has been proposed, such that an average of 0.025 mg/m^3 should not be exceeded. These standards are designed to protect the most sensitive individuals, including children, the elderly, and those with pre-existing heart or respiratory disease.

II. Purpose

The focus of this system is at the discretion of the health-care community. The data readings from the motion sensors are submitted to a database that determines which movements were made. With this environment, activities can be screened and utilized in a multitude of scenarios. Doctors' visits can be drastically reduced as data will be remotely collected and sent to the doctor's office. Rather than restricted and arranged movements, a more accurate representation of a patient's locomotion will be documented, as it was conducted in a real environment. Furthermore, many physical rehabilitation conditions may be arranged in the comfort of the patient's home. With respect to this, assisted living conditions may also be reduced, as patients with Alzheimer's can be tracked. If detected early enough, the intensity of some types of motor disabilities, such as Parkinson's and Duchenne Muscular Dystrophy, can be lessened. Moreover, obesity is an increasing disease, in which is part due to lack of activity. One could increase his or her exercise based on regulation of activity.

In addition to this, many risks for cardiovascular and respiratory disease that are the result of heavy exposure to high levels of air pollution can be monitored. As an example, this system can track where children spend their time and most physical activity (motion). The level of physical activity may be correlated with their inhalation rates of air pollutants. By combining an air particulate monitor sensor it is possible to reveal the air quality near playgrounds, parks, and other places children chose to spend their energy. This potentially allows us to objectively and accurately estimate the dose of $PM_{2.5}$ for each child who wears the system. It also allows us to understand, and possibly avoid or modify the environments, where children are most exposed.

Furthermore, short range communications can implement security protocols. The extreme difficulty to intercept the signals allows for considerable privacy. Being that medical matters are to be regarded as confidential and private, worry of gaining access to this type of information is negligible. Not only does the short range minimize interference, but it also enhances the portability of the wearable devices.

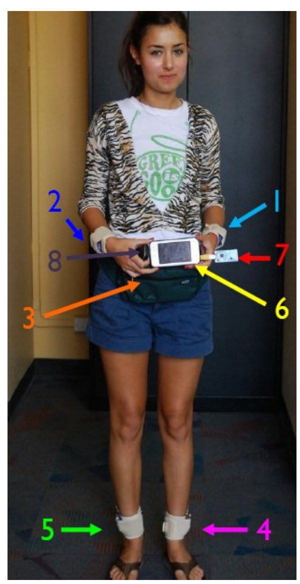
III. Architecture and Implementation

Using a Windows based machine, the installation of VMWare Player with a Maemo image is required for the Nokia N800 mobile device. Maemo is an open source software platform designed to work with mobile machines. The N800 essentially runs as a Linux station that can be SSHed to a PC for more comfortable keyboard and screen access.

A Body Sensor Network consists of several Telos motes (motion sensors), each one mounted with a custom-designed sensor board. The sensor board has a triaxial accelerometer and two biaxial gyroscopes. The system operates on the TinyOS operating system. The processing unit of each mote samples sensor readings and transmits the data wirelessly to a base station at a particular sampling rate[iii]. We use a tmote sky base-station, connected to the N800 through an OTG USB adapter. The motion sensors have been preprogrammed, enabling them to transmit their movement and acceleration data to the base-station in real-time, which is then forwarded to the N800 via USB. The ESSP Lab at the University of Texas at Dallas developed a script that enables the N800 to read and store the data from the motion sensors. At this point in the configuration, we have a basic assembly of a mobile Body Sensor Network. A GUI of the data signals is displayed, as shown in Figure 3.

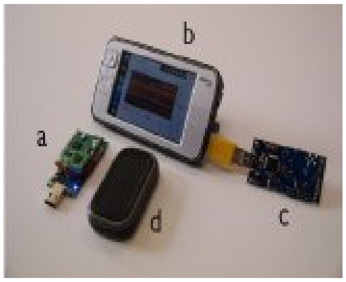
Moreover, the mobilization and practicality of the system is further enhanced by simultaneously collecting time-stamped longitudinal and latitudinal directions from the GPS device. We used the Nokia LD-3W GPS which connects with the Nokia N800 wirelessly via Bluetooth. The complete system is pictured in Figures 1 and 2. Once the data collection is finalized, the files stored on the mobile device can then be transferred to a PC (such as a doctor's) for further analysis. For a visual of the user's route, we wrote a script that parses the GPS data to a file that can be uploaded to a Google Maps API.

The air particle sensor (Met One Aerocet 531) is a larger, yet still mobile, device that computes the amount of particle matter in the air. This is separate from the mobile Body Sensor Network, but is an opportune device to combine with GPS tracking, as well as movement monitoring. The sensor logs the data internally with a time stamp that may be matched with the time stamps of the GPS data to provide geocoded $PM_{2.5}$ concentrations.



1. Sensor Mote 1
2. Sensor Mote 2
3. Sensor Mote 3 (in bag)
4. Sensor Mote 4
5. Sensor Mote 5
6. N800 (mobile device)
7. Base-station
8. GPS device

Figure 1



a. Telos mote motion sensor
b. Nokia N800 mobile device
c. tmote sky basestation
d. Nokia LD-3W GPS device

Figure 2

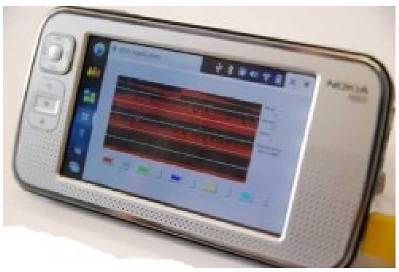


Figure 3

IV. Experiment

As a result of our research, we have developed a functioning mobile Body Sensor Network with GPS tracking. Several trials were made walking around the UC Berkeley campus in which the motion sensors monitored and recorded the subject's locomotion, whilst the GPS concurrently tracked the routes of the trials (Figure 4). Each of our trials successfully lasted from one to two hours without error or failure. However, the duration of the entire system is at the discretion of the batteries, ideally providing up to one to two days of continuous monitoring.

During the last trial around the Berkeley campus, we implemented the air particle sensor ($PM_{2.5}$). $PM_{2.5}$ concentrations ranged from 0.023 to 0.032 mg/m^3 at different times/locations during the walk (Figure 5). The largest dot translates as the area with the most particle matter and appears to have been along Hearst Avenue near a construction site. Clearly, this information is helpful in many respects. Downtown Berkeley, a more commercial/retail area, was originally perceived as the more polluted part of campus. Yet, in part due to the construction, an area that is visited by more pedestrians than vehicles renders a higher particle matter concentration. It is unclear whether the particulate concentrations measured during the walk are indicative of the general air quality at each of these locations, or rather just arose from being at the "wrong place at the wrong time", however, over multiple days of walking routes, we may find that indeed certain parts of the city may consistently contribute the most to an individual's exposure. If this is the case, then one result of this system could be the planning of alternative routes where the individual can avoid interaction with heavy pollution.

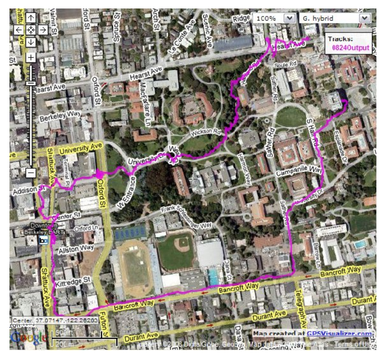


Figure 4

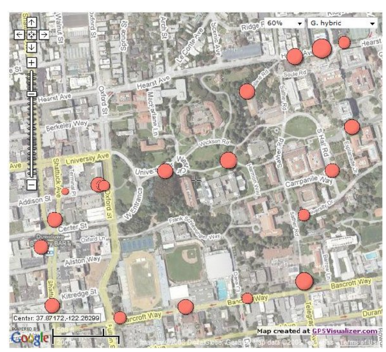


Figure 5

V. Known Issues

Due to an eight-week time constraint, a few issues arose that have not yet been properly assessed. To begin with, the complete system includes several language barriers. The Nokia N800 is designed for a Linux Maemo environment. This environment caters to the C programming language, including a scratchbox terminal that facilitates compiling C code. Fortunately, the LD-3W GPS device speaks C, which enabled us to integrate one device to the other. The most prominent consequence of the time constraint was the assimilation of SPINE into the system. As SPINE (described in section VII) is written in Java, it was difficult and too time consuming to create a way for the Maemo compiler to understand the SPINE code.

In terms of the hardware, a cold start-up of the GPS device took from ten to thirty minutes to connect. This connection must be initiated outdoors and must remain outdoors once connected. Although mostly accurate, there were some fallacies in the data received from the LD-3W. When plotted using the Google Maps API, seldom areas of the highlighted path deviated about ten meters of our actual route. In addition, the OTG USB connection to the base-station was very unstable. More often than not, when the base-station was inserted, it would not power. Even when powered, the N800 often did not recognize the USB port. We found no sound way of fixing this problem other than continually plugging and unplugging the base-station. Once connected and recognized, however, there were no issues disconnecting or separating from the N800. Moreover, if the N800 turned off unexpectedly (i.e. ran out of batteries) it would not power back on until thirty minutes of lying stagnant on the charger. If it still had battery life, we found that putting the N800 in the freezer for a few minutes would enable it to turn on.

Concerning the air particle sensor, care must be taken in comparing our data for short periods (2-minute samples as the subject was walking) with annual average standards for regional air quality monitors that are located at a fixed location and measure data continuously 24/7/365. It may be that the area near the construction in Figure 5 is a localized hot-spot that has persistently high concentrations. However, it also could be that the subject walked by during a short term puff of particulates such as a truck passing by at the same time. It is impossible to know without longer term sampling at that location. This highlights some of the methodological challenges in using wearable devices. We can note the subject's exposures as an individual, but it is more difficult to make generalized statements about the environment.

VI. Future Work

As our project develops, many of its expectations and functionalities will also expand. To start, Signal Processing In Node Environment (SPINE) is an open source software framework that builds Body Sensor Network applications. SPINE is designed to cater to mobile BSNs, and allows for many additional features to be added to the mobile BSN. Made available by Telecom Italia, this configuration is essential as it greatly expands the perimeters of the system. A SPINE-enabled system will allow the user features such as security preferences, 24/7 indoor/outdoor portability, complete usability, and is particularly marketable as new doors are opened even outside the healthcare community. SPINE is written in Java, whereas the LD-3W, N800 and corresponding Maemo environment are written in C. We will need to create a way for each device to collaborate with the other.

In an additional effort to create an efficient system, we will correct the problems surfaced during the initial trials. Of these corrections, we will use another Bluetooth GPS device that acquires signals better in an attempt to repair the issues currently associated with the LD-3W. In regards to the ambiguity of the data collected from the air particle sensor, a possible future solution is to develop and set up low-cost air quality monitors all over Berkeley that measured 24/7/365, as well as having the air particle sensor move with the subject. However, there are also some limitations with this approach related to the logistical difficulty of placing and securing these monitors. Another average we can compute is the average per person over time that demands wearable air quality sensors. Comparison can be based on different residential groups selected from the Port of Oakland, Downtown Oakland, and Berkeley for example, and then correlated with diseases.

VII. Conclusion

The integration between engineering and the medical sciences provides an array of possibilities to use personal devices to improve health. There is great demand within the healthcare industry for technology based on Body Sensor Networks, yet most applications thus far have been based on monitoring in well-defined spaces (e.g., indoor, close to a stationary gateway). A stationary gateway (e.g., one that is connected to a Personal Computer [PC]) restrains the user's travel and expediency. Mobile BSNs will expand the dynamics of healthcare applications by providing a means for accurate documentation of the range of indoor/outdoor movements over the course of the user's normal lifestyle. Furthermore, introducing GPS into the system will enhance existing applications, such as positioning during movement monitoring; whilst making room for new ones, such as integrating movement and location with other environmental sensors that may be used to document the user's exposures to environmental stressors (e.g., heat, noise, air pollution).

VIII. Acknowledgments

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IX. References

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