Data Fusion for Movement Visualization in a Remote Health Monitoring System

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Abstract. In this paper, we present a data fusion visualization infrastructure for sensor signals from a remote health monitoring system. The infrastructure involves wireless interfacing with the embedded sensor system, known as the Smart Shoe. It fuses and filters the data measured and then uses it to visualize with a graphics display the extracted walking and movement patterns. The various features of the visualization infrastructure are presented, along with the implementation challenges and details.

Keywords: Medical Embedded Sensing Systems, Remote Health Monitoring, Wireless Health, Visualization.

1 Introduction

The proliferation of low-cost sensors and wireless connectivity is helping to introduce real-time and remote health monitoring for a wide array of patients. A variety of sensored devices exist that can unobtrusively be incorporated into patient life and then wirelessly transmit data to caregivers and healthcare professionals.

In this work we focus our data fusion and visualization infrastructure on the Smart Shoe embedded sensor system. The Smart Shoe is a lightweight sensing system aimed at extending fall risk analysis and human balance monitoring outside of a laboratory environment.

The current system monitors walking behavior to generate fall risk estimates, by using collected ambulation data values to extract correlations with features identified by geriatric motion experts as precursors to balance abnormality and fall risk [13] [14]. Additionally, the Smart Shoe has been used for neuropathy management [3] [4] and can be used for fine-grained weight fluctuation detection, which has been shown to be important for weight and cardiovascular system monitoring.

In our infrastructure, we wirelessly collect raw sensor signals from the Smart Shoe, either through a handheld device gateway or directly using the computer used for visualization. The data is them filtered and fused to enable graphical visualization of the walking and movement patterns of the Smart Shoe sensor system.

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There are three distinct advantages to the use of a visualization approach for data analysis in this scenario. First, the visualization enables physicians and caregivers to assess walking patterns in a convenient and affordable manner. The graphics software includes features such as changing the angle of view, which would impossible to do in any other context. Potential views include, separating one shoe from the other, looking under the soles of the shoe while walking is taking place, and examining the movement of the foot from the side.

Second, the visualization software enables the researchers and caregivers to assess the quality of the data collected from the Smart Shoe system in an efficient manner. With visual inspection invalid data values can be easily spotted, and thus removed to prevent skewing of the data analysis results. The sheer volume of data collected using the Smart Shoe specifically, and all other embedded health sensing systems generally, is astounding. Ensuring the validity of the data values can be an intimidating task; however, it is critical in health applications, considering that medical decisions for medication, hospitalization, and limitation of mobility can results from the assessment of the Smart Shoe system data values. By enabling a fast and efficient visualization of the data results, human users can reliably identify any abnormalities in the sensor data collection.

Finally, the infrastructure presented in this work has been used for Smart Shoe system development. The visualization and data fusion software and algorithms have been used to further enhance the development of the sensor system, including modifications to the placement of the system sensors and testing of the Bluetooth wireless transmission.

In the remainder of this paper, we present in detail the system infrastructure and components, with a special focus on the data fusion and graphics infrastructure.

2 Related Work

The Smart Shoe developed at UCLA has been used for various other applications. These include application to balance and fall risk assessment [13] [14], as well as monitoring foot placement in patients suffering from neuropathy [3] [4]. Smart Shoe data has also been used for event detection algorithm development and experimentation [15].

There exist other research systems that have examined visualization of movement and gait patterns in patients. With the Smart Cane system [1] [9] [17], the motion of the cane was displayed on a tablet PC for the purpose of system development and demonstration.

There exist various visualization software systems that visualize gait pattern data, but not using a graphics interface as we have done. These include [12], which uses a graph structure to display course-grain changes in gait over time. Dejnabadi et al carryout full gait visualization using accelerometer and gyroscope data, but no data from pressure sensors [5].

Data fusion in other embedded sensor systems has been explored previously. Projects include the environmental monitoring systems [6] [7] [8] [10] [16] and the in-home patient monitoring systems [11].

3 System Infrastructure

3.1 Smart Shoe

The Smart Shoe, shown in Figure 1, is an orthotic shoe developed at UCLA [3] [4] [13] [14]. Through the use of 3-axis gyroscope, 3-axis accelerometer, and a few well-placed pressure sensors, shown in Figure 2, the Smart Shoe is able to monitor foot motion and pressure distribution to evaluate the state of a patient. It wirelessly connects via Bluetooth to smart phones or other computing devices for data processing, visualization, and network connectivity.

The Smart Shoe is a lightweight infrastructure aimed at extending fall risk analysis and human balance monitoring outside of a laboratory environment. It is also used for detecting balance trends over time and alerting patients of improper foot placement. Additionally, the Smart Shoe can be used for fine-grained weight fluctuation detection, for weight and cardiovascular system monitoring.

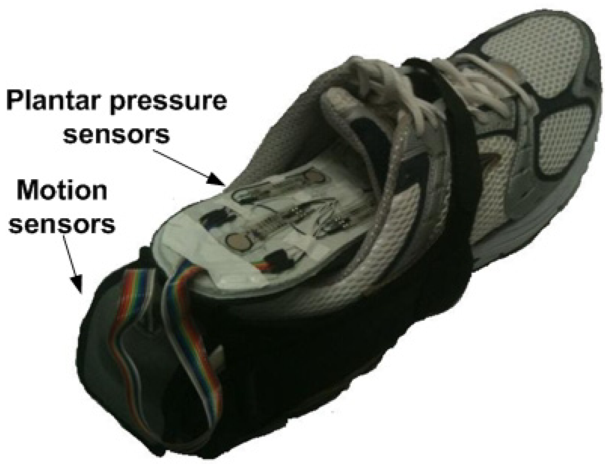


Fig. 1. Smart Shoe System [15]

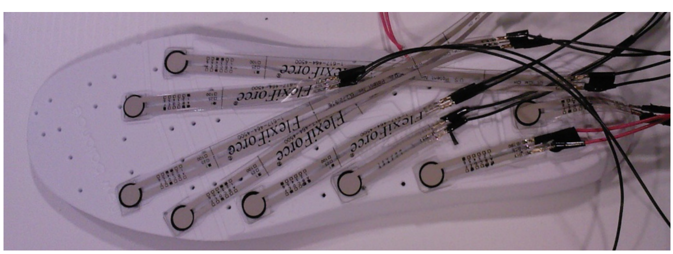


Fig. 2. Smart Shoe Insole Pressure Sensor Locations [14]

3.2 Overall System Functionality

A high-level overview of the overall functionality of the visualization infrastructure presented in this paper is given in Figure 3. As shown, sensor signals from the Smart Shoe are wirelessly transmitted to a computer, where visualization and data storage can be accomplished. The transmission of the data can be done in one of two ways. Using the Bluetooth transmitter on the smart shoe, sensor data can be transmitted directly to the computer.

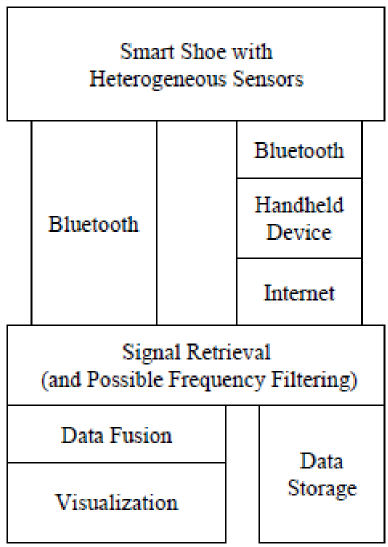


Fig. 3. Top-Level View of the System Interactions, from Sensor Data Collection to Wireless Transfer, to Visualization and Storage

Additionally, data from the smart shoe can be sent to a handheld device, including a smart phone. The data can then be transferred to a remote server or the computer with the visualization software. The advantage of this approach is that the computer with the visualization software does not need to be in the presence of the Smart Shoe. To the contrary, caregivers can visually monitor the motion of the patient remotely and conveniently.

Previous to our visualization infrastructure, data collected from the Smart Shoe was collected from the sensor system and then archived. The results were then used for various applications, including imbalance detection and activity monitoring. However, with this additional work, the data can be fused for data visualization using a user-friendly and interactive graphics interface.

3.3 Data Fusion

The sensors used in the Smart Shoe are heterogeneous, including accelerometers, gyroscopes, and pressure sensors. Additionally, the sensor signals are transmitted over a wireless connection either directly or indirectly to a computer. Transmission over the Bluetooth connection can be lossy. Additionally, the data collected from the various sensors are not necessarily time-synced with each other. All of these challenges with the sensor signals require post-processing of the data using a data fusion approach. Using statistical inference and model generation, x-y-z movement in space is created for eight data points. These values are then used for the visualization software.

3.4 Graphical Component

In this section, we present the interactive graphics visualization component of our infrastructure. Screenshots from the software developed is given in Figure 4. The Figures 4a and 4b demonstrate two different screenshots over time, as the patient moves the left foot to walk.

It is possible for the user of the software to change the angle of view, using mouse clicks and keyboard clicks. As shown in Figure 4, a view of foot motion from the bottom of the shoe can be shown, a perspective that would physically not be possible.

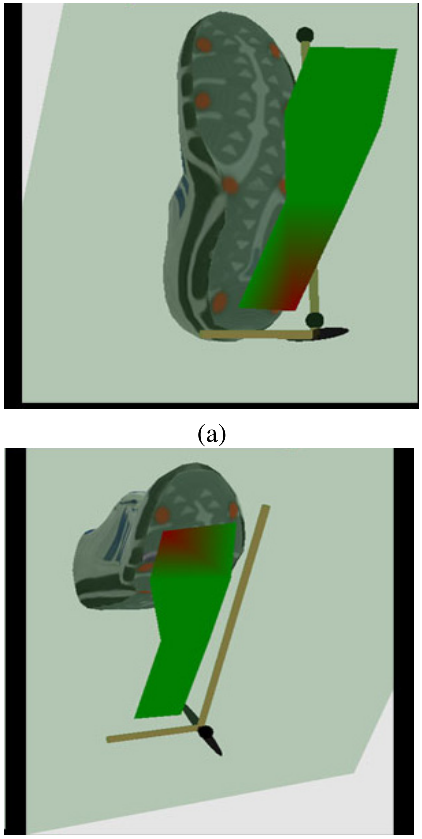
The dynamic pivot feature allows for the view changes. A grey bar at the end corner of the screen is used to represent the current location of the pivot. The location can be selected from a range of values, and with more than two values selected the center of mass of those selected points is calculated. In other words, the shoe is given three rotational values (x,y,z), and the values entered by the user are used to determine the point around which to pivot the shoe.

The user can modify is the number of feet that are to be viewed at a time. One or both feet can be viewed at a time.

It is possible to change the quality of the shoe graphics. With an online execution of the software, data filtering is used to limit the computation complexity of the data fusion, and hence enable online interaction between the visualization software and the Smart Shoe. In the case of offline visualization, the highest quality of visualization is to be used, for the most precise and complete examination of the data.

A summary of the interactive software features developed are given in Table 1. Additionally, we have uploaded two videos of the software execution to You Tube [18] [19]. The videos demonstrate a range of views that are possible, as well as the quality of the graphics software developed. They also highlight the ease with which invalid data values can be spotted.

The software takes into account collision detection with the ground. Specifically, it corrects for missing or flawed data, where the data appears to demonstrate that the shoe is moving past the ground. This collision detection algorithm can be used outside of the visualization software, in dynamic calibration of the sensors, specifically for the accelerometers. In the case of ground collision detection, recalibration of the sensors is signaled and carried-out without halting data collection. A related approach for in situ calibration of sensor systems has been examined before [2].



(a)

(b)

Fig. 4. Graphics Visualization Software Screen Shots: Demonstrating the Change in Shoe Movement as the Patient Walks

Table 1. Graphical Software Feature List

Feature Name	Feature Description
Dynamic Pivoting	Changing the view from which the shoe(s) can be viewed
Shoe Number	Displaying one or both feet to the screen at a time
Graphics Quality (i.e. online or offline execution)	Decreasing the quality of the animation by filtering the data values, for the sake of a more responsive online version of the software.
Data Source (i.e. remote or local)	Using data values collected using the machine's Bluetooth connection or picking up data values off of a remote server (which were collected from the Smart Shoe using a handheld device in the field).

4 Implementation

The implementation of the visualization involves two related parts, first fusing the heterogeneous sensor signals and then displaying them graphically.

The graphics are implemented with a polygon structure across the sole of the shoe, with a relatively small number of polygons. With some iterative exploration, three polygons were found to provide enough visual accuracy, while still enabling efficient online execution of the program.

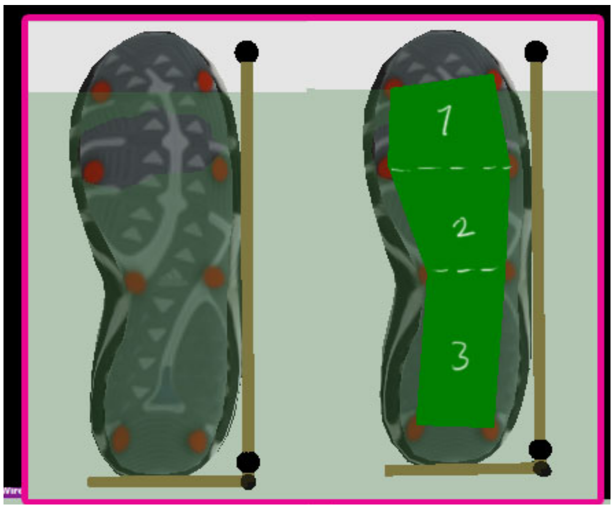


Fig. 5. Polygon Structure Overlaid the Shoe Graphics

Figure 5 demonstrates the locations of the polygons. As can be noted from the figure, the locations of the pressure sensors in the shoe insert, shown in Figure 2, are different from the end points of the polygons, displayed with red dots, in Figure 5. Additionally, the accelerometers and the gyroscopes are located at the back of the shoe, where there is no designated polygon.

As a result the graphics implementation required the manipulation and fusion of the data values obtained from the shoe sensors. Most notably the pressure sensor values and the movement sensor data was fused and then extrapolated to the eight movement points shown. The values of the movement points are then modified in the three-dimensional space, depending on the input sensor signals. The movement of the remainder of the shoe is dictated by the existing model for the shoe.

The red dots, which indicate the manipulation points, where chosen as they enabled full movement of the shoe. If desired, the third polygon can be extended to cover the bottom of the shoe completely. However, this is not the most natural point of motion for people.

5 Future Work

There exist several extensions to the work we are considering, in addition to the most general plan to apply our approach to other wireless health systems.

With the expansion of the Smart Shoe to fine-grain weight fluctuation detection, the data fusion approach can be leveraged for analyzing and visualizing patient weight changes and activity levels for the purpose of in-home congestive heart failure monitoring.

Finally, as a significant enhancement to the Smart Shoe, we plan to use our collision detection algorithm and software to enable dynamic Smart Shoe calibration to deal with accelerometer drift.

6 Conclusion

In this paper, we presented an efficient sensor data fusion and visualization approach, specifically for sensor signals collected from the Smart Shoe system. The system requirements that led to our fusion of non time-synced and heterogeneous sensor signals were presented. The various components of the infrastructure, including the data processing and graphical display were highlighted, including the implementation details of the graphics visualization.

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