SmartSpaghetti: Use of Smart Devices to Solve Health Care Problems

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***Abstract*—Mobile devices such as smartphones have a number of sensors that can be exploited to solve a number of problems related to health care delivery. In this paper we use accelerometer, gyroscope, and compass sensors on smartphones to solve a location tracking problem common to many emergency departments. An emergency department typically has unique characteristics including not being friendly to be visually surveyed, since the layout consists of many isolated islands and the workstation layout is not standardized. The spaghetti diagram is a tool to help to identify areas where time can be saved by visualizing unnecessary movement of products, staff or patients. We report the development of an automated tool to create spaghetti diagrams of movements of personnel in a non-intrusive way. A preliminary prototype to produce paths showed very encouraging results. We also identify challenges and our approach to meet them.**

***Keywords*-Mobile Health, Spaghetti Diagram, Inertia Sensor, Indoor Tracking.**

I. Introduction

Delivering high quality, economically-efficient healthcare is rapidly becoming one of the key economic, societal and scientific challenges in the United States as well as globally. Therefore, several federal government agencies recently focused on accelerating the development and use of innovative approaches that would support the much needed transformation of our healthcare system. For example, the need for significant healthcare transformation was recognized by numerous organizations including the President's Council of Advisors on Science and Technology (PCAST), National Research Council (NRC), Institute of Medicine (IOM), Computing Community Consortium (CCC), and the National Academy of Engineering [1]. To facilitate the transformation, there have been continuous efforts to advance computing research in healthcare, by enabling collaboration among cross-community that includes biomedical informatics, computer science, clinical medicine and public health [1].

Improving the quality and the efficiency of the healthcare system requires new management systems. Many leading healthcare institutions, therefore, follow a management approach called *Lean*, which is a quality improvement philosophy based on the Toyota Production System that processes to maximize customer value while minimizing the waste. Recent studies [9], [10] show that adoption of lean management helps healthcare organizations to improve their process and outcomes, reduce costs, and increase satisfaction among patients, providers, and staff. One of the fundamental concepts of *lean* management is to exploit the resources (e.g., lab equipment, medicine, time, money, staff, etc.) efficiently. In this paper, our focus is to identify opportunities and directions, where we can exploit smart devices (i.e. smartphone, smart gadget etc.) to improve *Lean* – healthcare management.

Like other industries, the healthcare industry is experiencing the effects of smartphones. Indeed, healthcare may be among those industries where the impact has been most profound. One market research firm estimates that 81% of US physicians in 2012 use smartphones [2]. In another study, 85% of medical providers working in Accreditation Council for Graduate Medical Education training programs reported use of smartphones [3]. A recent study on the role of smartphones in medicine [4], shows that the amount of research in the use of smartphones in medicine is rapidly growing and smartphones have a very bright future in the world of medicine, where doctors, engineers, and others alike continue to contribute more ingenuity to this dynamic field. Given the numerous ways in which the smartphone can be utilized in healthcare, we believe that smartphones will become diagnostic and therapeutic tools that are as irreplaceable as the stethoscope has been in the practice of medicine.

Other than smartphones, research firms such as ABI Research anticipates that by 2016 there will be more than 100 million wearable health-related devices sales annually [5]. They also projected 80 million wearable sports and fitness related monitoring devices sales by 2016 [6]. The availability of new inexpensive smart gadgets that monitor your health and fitness will range from heart monitors to biosensors that read body temperature and motion.

We envision that *Lean* management systems will leverages the potentiality of smartphones, smart gadgets, wearable devices. As an example, in this paper we focused on using smartphone technology to facilitate the creation of an important *Lean* management tool called a "Spaghetti Diagram." As a part of our goal, we want to leverage the smartphone's inertia sensors (i.e accelerometer, gyroscope, magnetic sensor, etc.) to generate a Spaghetti Diagram in an automated, low cost, low overhead, and transparent way. In section 2, we describe more details about the Spaghetti Diagram tool.

II. Background

A. Spaghetti Diagram

The spaghetti diagram is a tool to help establish the optimum layout for a department or ward based on observations of the distances traveled by patients, staff and/or products (e.g., x-rays). Spaghetti diagrams expose inefficient layouts and identify large distances traveled between key steps. This tool helps to identify areas where time can be saved by visualizing unnecessary movement of products, staff or patients. The time saved can be used more effectively to provide value and therefore can help to reduce delays, increase efficiency and productivity and thus improve patient care. The spaghetti diagram is actually a simple value stream-mapping tool for "Lean Process Improvement" [9].

Figure 1: Laboratory inside Hospital (source: Wikipedia).

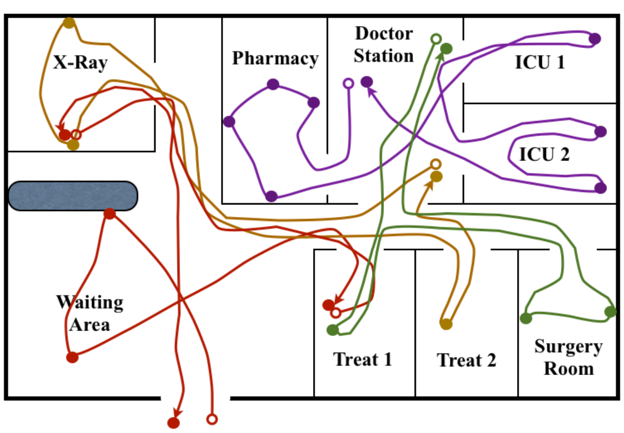

Figure 2: Spaghetti Diagram.

Currently, the spaghetti diagram is created manually in which the movements of the staff member or patient are visually observed, and then, are manually drawn as lines on the layout diagram of the area under concern. This traditional way suffers from several challenges including: i) the layout of some areas (e.g., the emergency department (ED)) is not friendly to be visually surveyed; ii) the layout consists of many isolated islands; and iii) the workstation layout is not standardized.

B. Indoor Tracking or Localization

There have been numerous studies on indoor localization/-tracking that leverage the signal strength of an RF signal from different nearby RF sources or infrastructures (e.g., WiFi Access point, Cellular Tower) [13], [12], [11], [7]. These RF based schemes accompanied with sophisticated localization algorithms could achieve accuracy with an error of 6-8m, which is insufficient for our scenario of generating the spaghetti diagram in an ED environment. Moreover, such indoor localization system require additional infrastructure support which is an overhead to the existing management system. Therefore, unlike the existing indoor localization or tracking system we wanted to leverage the commonly used smartphones and already existing infrastructure to generate the spaghetti diagram.

III. SmartSpaghetti System

In the SmartSpaghetti system, we utilize the smartphones carried by physicians and staff members to detect and track their movements and map these movements to flow paths. More specifically, the human movement path can be modeled and segmented into units of strides and turns as shown in Figure 4. In our system, we utilized the smartphones sensors such as accelerometer, gyroscope, and compass sensors to track the human movement path regardless of the orientation or position of the phone.

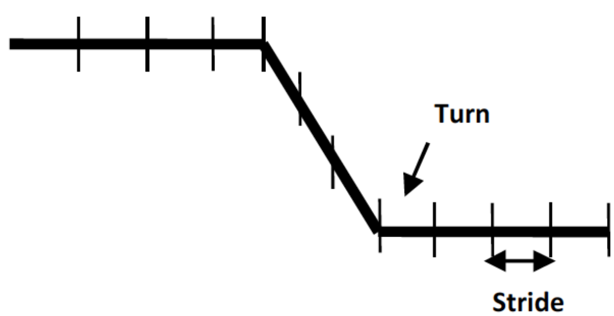

Figure 4: Human Movement Path Model.

We can summarize the overall flow of our SmartSpaghetti system in the following main steps:

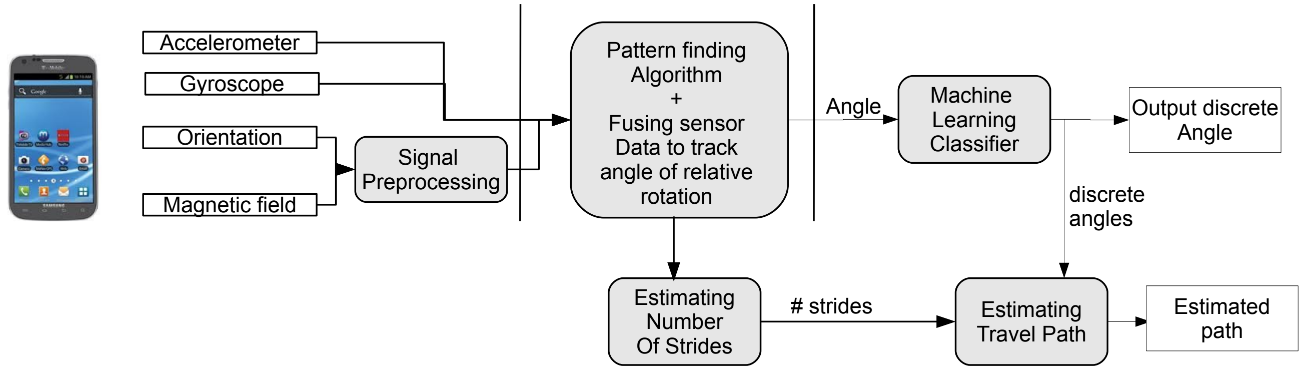

Figure 3: System architecture.

- Collect sensor readings from the individuals smartphone.
- Process the collected data to extract movement information such as strides, directions, and pauses of individuals.
- Generate the Spaghetti Diagram by drawing the corresponding movement paths on the map layout.

A. *SmartSpaghetti: Architecture & Approach*

Figure 3 shows the architecture of our *SmartSpaghetti* system. The whole system has mainly two functionalities, the first is to estimate the number of strides, and the second is to determine the angle of a user's turn. In both processes, we utilize a number of sensors on the smartphone. In the system, we apply signal processing (i.e. low pass, high pass filter), pattern recognition (i.e. Dynamic Time Wrapping [14] Algorithm), sensor fusion, and machine learning/classifier on the raw sensor data to detect the user's stride and the angle of turn.

In detecting a user's strides, we apply a Dynamic Time Wrapping (DTW) [14] algorithm on the raw accelerometer sensor readings to find out a stride pattern. Before applying the DTW algorithm, we apply low pass filter on the sensor readings to reduce the impact of high frequency noises. On the other hand, we use the phone's gyroscope, orientation and magnetic sensor to detect the angle of a user's turn movements. Initially, we use a sensor fusion technique to calibrate the sensor readings, then we applied a machine learning technique to classify or map the change of sensor readings to a certain angle of movement of the user.

Figure 5 shows the corresponding raw data from the accelerometer sensor versus time (tenth of a second) for a walking individual while the smartphone is in her pocket. From this raw data, we can detect the taken number of strides as well as the corresponding time. Similarly, the orientation/compass sensor is utilized. Figure 6 shows an example of the collected raw data and the corresponding information.

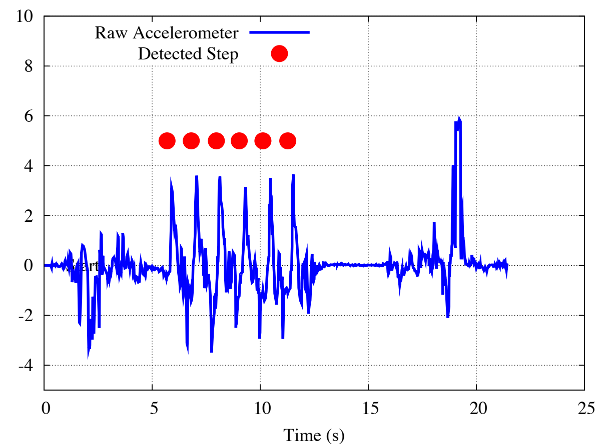

Figure 5: Accelerometer sensor raw data with detected steps.

IV. Preliminary Prototype & Experiments

We ran a set of preliminary experiments at both Old Dominion University (ODU) and the Childrens Hospital of The Kings Daughters (CHKD) as a proof-of-concept of our scheme. In the following, we show the performance of the preliminary implementation of our scheme.

A. *ODU Experiments*

Figure 7 shows the first experiment at ODU. In this experiment, the user, while the phone is in her pocket, moved along a square area shown as a black solid line in the figure. The estimated path by our implementation prototype is shown as a sequence of small red squares. As shown in the figure, the detected path matches the actual path with very high accuracy. Similarly, Figure 8 shows another experiment with a different moving path.

Figure 9 shows results of another experiment at ODU. In this experiment, we tracked the movement of the user while

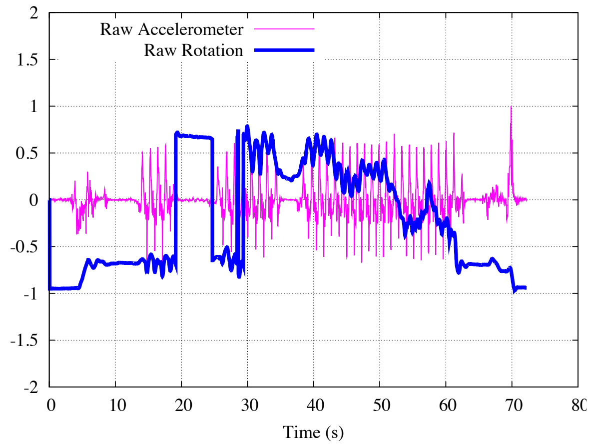

Figure 6: Interpretation of orientation sensor raw data.

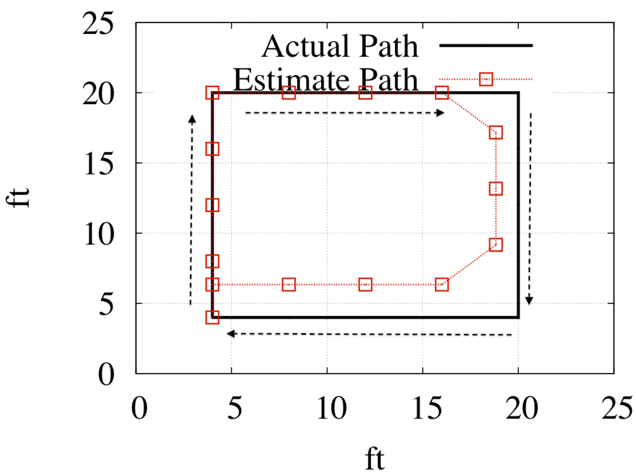

Figure 7: Walking experiment at ODU.

he walked across the 3rd floor of the Computer Science Building. As shown, the estimated path (shown in red) matches the steps taken by the user.

B. CHKD Experiments

Figure 10 shows a portion of the Emergency Department on the first floor at CHKD where we conducted two preliminary experiments. The path of the first experiment is within the red oval while the path of the second experiment is show in the blue circle. In the following, we show the results of these two experiments.

Figure 11 shows the results of the first experiment. Two users, each with the phone in their pocket, walked together from the Start point to the Stop inside the destination room. As shown, both the estimated paths (shown as the red and pink paths) match the actual path (shown as the green path) taken by the users.

Figure 12 shows the results of the Second experiment. In this experiment, a single user moved along a certain path in which he paused at three stops along his walk marked with small blue squares. As shown in the figure, the estimated path (shown as the red path) matches the actual path (shown as the green path). In addition, the exact time of the pauses taken by the user were measured and shown on the graph as well (i.e., 10 sec, 7.8 sec, and 2.7 sec). It is noteworthy that our system not only accurately captured the path, but also automatically captured the time spent at a location, which would be very laborious to capture from a videotape review.

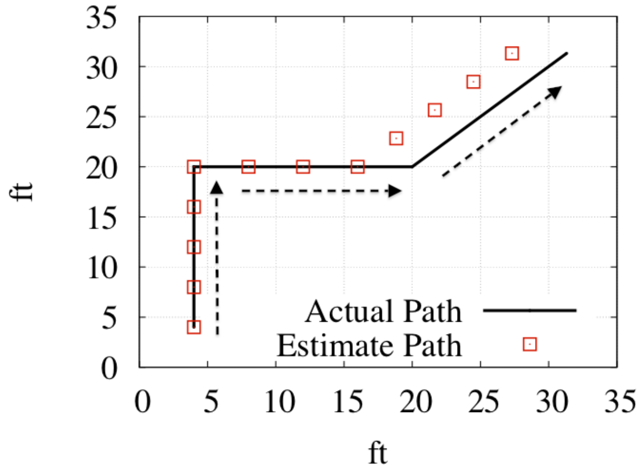

Figure 8: Second walking experiment at ODU.

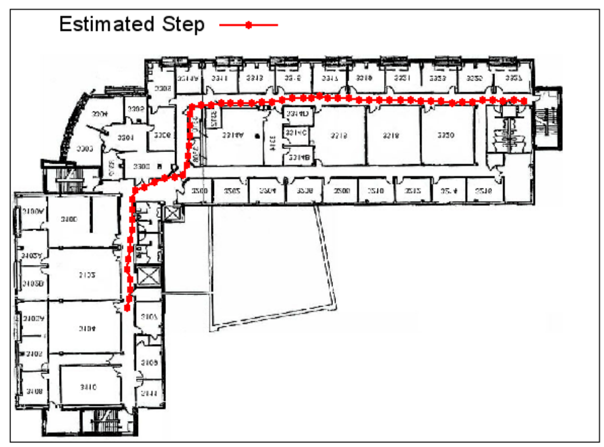

Figure 9: Movement tracking experiment at ODU.

V. Discussion

Throughout the different experiments, we found that detecting the user stride from the raw sensor reading is not that challenging. However, to convert the number of strides to the actual distance traveled by the user is a challenging task. In order to address this challenge, we need to map a

Figure 10: Part of Floor plan at CHKD with paths.

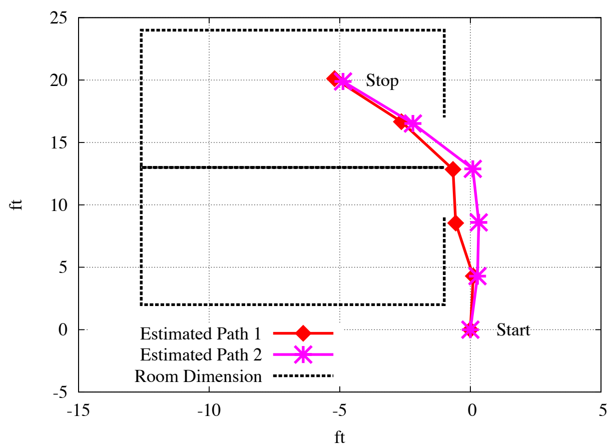

Figure 11: Movement tracking of the first experiment at CHKD.

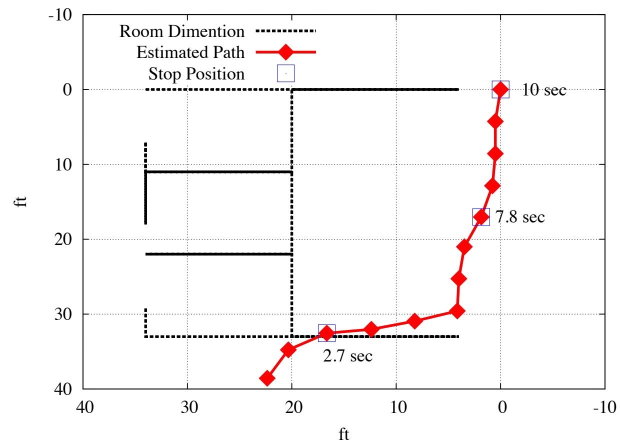

Figure 12: Movement tracking of the second experiment at CHKD.

stride to a distance, which is called stride length. The stride length varies from user to user based on their height and weight. Even for the same user stride length can vary with the speed of walking. There are existing model that map user stride length with the user's height, weight, and speed of movement. In future we would like to to apply these models to improve the accuracy of the spaghetti diagram.

Detecting the angle of a user's turn, regardless of the orientation and the position of the smartphone, is another challenging problem. The smartphone has its own co-ordinate system that is totally different from our own world co-ordinate system of North-East-Gravity. In addition, the human walking also has a separate coordinate system that represents the Forward Direction-Side-Gravity. Now, our main objective is to find the relative rotation/turn of the user's movement with respect to the human's walking coordinate system. In the future, we wanted to exploit the inertia sensor of the smartphone to detect the user's turn by leveraging these different coordinate systems.

VI. Conclusion & Future Work

In this paper, we showed that smartphones can be used in an automated, non-intrusive manner to generate spaghetti diagrams for a hospitals emergency department. This paper only reports on the results of experiments with a preliminary prototype and a number of challenges remain in order to create a highly accurate system implementation. Among these challenges are the following:

- The system has to be user and device independent such that no training is required either for a new user or a new device.
- The system has to be independent of the smartphones orientation/position.
- To enhance system accuracy, several error correction schemes could be applied:
  - Ideal paths: Know all possible paths ahead of time and select the best path among all possible paths.
  - Confirm location as the user moves through other detection or orientation systems, such as:
    - ∗ Fusing with other technologies:
      - · (WiFi [7], Sound [8], and Bluetooth)
      - · A WiFi Cisco infrastructure is deployed at CHKD.
    - ∗ Use of anchor points.
    - ∗ Enhanced machine learning scheme for estimating location.

Once surmounted, this smartphone application can be used to help improve the layout and efficiency of healthcare operations. In addition, this type of smartphone application could be applied in a wide range of industries to improve their understanding of how work is conducted and how it can be improved to increase productivity.

REFERENCES

[1] Smart and Connected Health (SCH), http://www.nsf.gov/pubs/2013/nsf13543/nsf13543.htm, 2013.

[2] Kiser K, *25 ways to use your smartphone, Physicians share their favorite uses and apps*. Minn Med 2011 Apr, 94(4), 22-29.

[3] Franko OI and Tirrell TF, *Smartphone App Use Among Medical Providers in ACGME Training Programs*, Journal Med Syst 2012 Oct, 36(5), 3135-3139.

[4] Ozdalga E and Ozdalga A and Ahuja N, *The Smartphone in Medicine: A Review of Current and Potential Use Among Physicians and Students*, Journal Med Internet Res 2012, 14(5):e128.

[5] ABI Research, *Wearable Wireless Medical Devices to Top 100 Million Units Annually by 2016*, https://www.abiresearch.com/press/wearable-wireless-medical-devices-to-top-100-milli, August 2011.

[6] ABI Research, *Wireless Health and Fitness*, https://www.abiresearch.com/research/product/1005339-wireless-health-and-fitness/, June 2011.

[7] Youssef M. and Agrawala A., *The Horus location determination system*, Journal Wireless Networks archive, Volume 14 Issue 3, June 2008.

[8] Uddin M. and Nadeem T., *RF-Beep: A Light Ranging Scheme for Smart Devices*, The 11th IEEE International Conference on Pervasive Computing and Communications (PerCom '13), SanDiego, CA, March 18-22, 2013.

[9] John S. Toussaint, and Leonard L. Berry, *The Promise of Lean in Health Care*, Mayo Clinic Proceedings, Volume 88, Issue 1, Pages 74-82, January 2013

[10] James P. Womack et al., *Going Lean in Health Care. IHI Innovation Series white paper*. Cambridge, MA: Institute for Healthcare Improvement; 2005.

[11] P. Bahl and V. N. Padmanabhan, *Radar: An in-building RF-based user location and tracking system*, in INFOCOM'00: the 19th Annual IEEE Conference on. Computer Communications, tel-Aviv, Israel: IEEE Infocom, March 2000.

[12] G. Borriello, A. Liu, T. Offer, C. Palistrant, and R. Sharp, *Walrus: wireless acoustic location with room-level resolution using ultrasound*, in MobiSys '05: Proceedings of the 3rd international conference on Mobile systems, applications, and services, new York, NY, USA: ACM Press, 2005, pp. 191-203.

[13] Y. Ji, S. Biaz, S. Pandey, and P. Agrawal, *Ariadne: a dynamic indoor signal map construction and localization system*, in MobiSys'06: Proceedings of the 4th international conference on Mobile systems, applications and services, new York, NY, USA, 2006.

[14] P. Senin, *Dynamic time warping algorithm review*, University of Hawaii at Manoa, Tech. Rep., 2008.