Towards Improved Performance and Compliance in Healthcare using Wearables and Bluetooth Technologies

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ABSTRACT

Performance and compliance in hospitals are particularly challenging due to the nature of care variability, and the human-intensive clinical activities involved. There is a need to collect fine-grained measurements to enact performance and governance effectively.

Modern wearable technologies, such as smart watches, provide a significant opportunity towards facilitating the gathering of such fine-grained data points such as location. However, indoor localization using wearables is limited due to many factors, including signal sensitivity, interference, and variations in manufacturers specifications.

This paper introduces a domain problem from healthcare, demonstrates empirically the limitations with today's wearables, and outlines novel approaches to dealing with such limitations. Specifically, we demonstrate how modern wearables can be deployed to collect fine-grained performance measures and facilitate governance.

Categories and Subject Descriptors

J.3 [**Life and Medical Sciences**]: Medical Information Systems.

C.3 [**Special-Purpose and Application-Based Systems**]: Signal Processing Systems.

General Terms

Design, Management, Measurements, Performance.

Keywords

Wearables, Healthcare Informatics, Bluetooth, RSSI, Compliance, Governance, Indoor Localization, High Efficiency Healthcare, Electronic Healthcare Records, Performance Management.

1. INTRODUCTION

Performance management in hospitals today is complex and challenging. There is inherent variability regarding the delivery of care. Patients' characteristics, disease complexity, existence and interactions with other medical conditions, and many others are among the factors that contribute to this variability.

Despite the fact that hospitals today collect a large amount of data, such data is frequently 1) at high level of granularity making root-cause analysis difficult 2) collected ad-hoc and after-the fact, too late for supporting timely decisions 3) based on a paper-trail, with inaccurate time-stamps that do not reflect operational realities.

The emergence of wearable technologies such as smart watches and smartphones presents an opportunity for collecting fine-grained data points for supporting timely decisions. However, the potential of wearables to enable performance management and governance in hospitals has not reached its full potential.

Wearable technologies are experiencing increasing levels of adoption by the general public. Wearables enable users to track information about their health and activity. Major wearable manufacturers are developing applications to facilitate data integration between such wearables and care providers. However, the adoption of wearables inside hospitals for performance and governance remain limited.

In this work, we explore the potential of wearables to address some of the pressing performance and compliance challenges inside hospitals. This paper presents a reference problem statement (section 0), and empirical investigation of the applicability of Wearables (section 4), and outlines an approach for adopting Wearables in healthcare for performance management and governance (section 5).

The problem statement is developed in collaboration with a large urban hospital in North America and highlights the requirements for managing clinical performance at a walk-in clinic. The problem has two aspects, one aspect related to performance management, and the other related to governance and compliance.

The empirical investigation attempts to evaluate the applicability of today's Wearables in solving the stated problem. Key limitations are identified and demonstrated. The proposed approach is designed to handle modern wearable limitations and paves the way for wider wearable adoption inside hospitals.

A walk-in clinic accepts patients as they present themselves at the reception, or by appointment. Physicians working at the clinic are expected to see a specified number of patients daily, based on the complexity of the patients' disease and condition.

The condition complexity is judged subjectively by the treating physician, and is reviewed by the management. The condition complexity is in part related to a classification of conditions and appointment type (follow up, annual check up, new patient, etc.).

The specific challenge faced by the clinic is described in the following two sections.

1.1 Performance Management Problem

Physicians contracted by the hospital are compensated based on 1) the number of patients they see and 2) the complexity of the patient condition. The hospital has developed an extensive classification of the complexity of conditions associated with patient visits.

Both hospital management and care providers recognize that this performance measure can be inaccurate. The complexity can vary significantly between different patients with the same classification. In addition, this performance measure creates a counter-productive incentive; physicians may attempt to see as many patients as possible ignoring other important measures, such as re-admission rates, patient satisfaction and outcomes.

An alternative measure of condition complexity is the time duration spent with the patient. Complex conditions may require the physician to walk to his or her office to look up information and/or to order specialized tests. A complementary performance measure is how many times the physician has walked from and to his or her office during the patient visit.

Specifically, the clinic would like to collect the following fine-grained data points for each patient visit:

1. The time duration a physician spent in the examination room.

2. The number of times the physician walked to and from his office and back to the examination room.

3. The cumulative time duration the physician spent in his office during the patient visit.

To satisfy the above stakeholder requirements, we identify the following key system requirement.

Key Requirement #1: The system must identify physician walk-in and walk-out incidents and calculate total duration spent inside the room and office.

1.2 Compliance and Governance Problem

At the clinic, physicians are required to sanitize their hands before and after each patient encounter. Currently, the clinic measures compliance by two means: 1) through the measurement of sanitization fluid consumption; 2) by random manual observation of physician sanitization practices. The first method is imprecise, as it does not inform management of particular compliance or non-compliance behavior by physicians. Moreover, the method does not expose potential patterns in compliance (i.e., day shifts vs. night shifts). In addition, the data available in this method is only ready up to a few months after the fact. The second method (manual observation) is time consuming, and suffers from the risk that behavior changes during those observation sessions.

The clinic would like to 1) monitor hand sanitization compliance in real-time, and 2) remind physicians of non-compliance in time for a corrective action. To satisfy the above stakeholder requirements, we identify the following key system requirement.

Key Requirement #2: The system must record sanitizer utilization, and remind physicians before and after patient encounters.

2. OVERVIEW OF PROXIMITY-BASED APPROACH

To fulfill the system requirements described in the previous sections, we propose a Bluetooth based indoor localization solution. We developed a Proximity-Based system that collects location information and communicates the data with a rule engine that infers additional information.

For example, with regard to the compliance to hand sanitization, Bluetooth beacons are installed inside the hand sanitizer stands and communicate with a Bluetooth receiver on a watch or a phone carried by the physician (Figure 1).
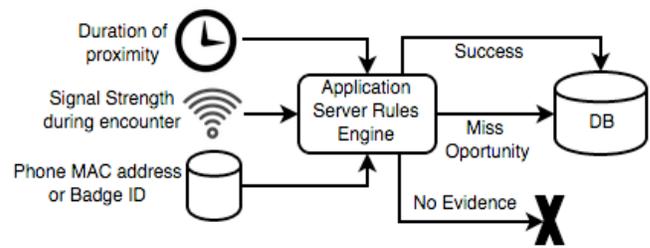

Figure 1: Overview of Rule Engine

The Rules Engine relies on the duration of the encounter and the signal strength to determine whether the sanitizer was utilized.

We instrumented six hand sanitizers in the lab, representing a section of the walk-in clinic as shown in Figure 2.
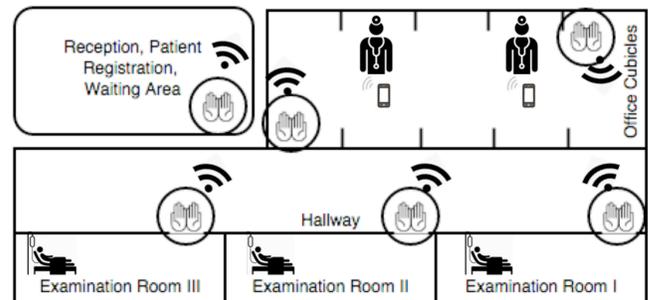

Figure 2: Bluetooth and Beacons Deployment

In order to ensure that the system correctly measures sanitizer utilization, our team conducted an initial investigation related to the correct positioning and number of beacons. Indeed, previous studies have demonstrated that signal interference among beacons could falsify measures [7]. The remainder of this paper focuses on this particular problem and proposes a solution.

3. EMPIRICAL INVESTIGATION OF MODERN WEARABLES FOR INDOOR LOCALIZATION

A key premise in the proximity approach is the consistent correlation between signal strength (as measured by the Received Signal Strength Indication (RSSI)) and the distance between the beacon and the receiver. In this section, we present an investigation of a number of wearables in terms of correlation between RSSI and distance.

3.1 Single-Beacon Installation

In this set up, we measure RSSI and distance in the presence of a single beacon. RSSI correlates proportionally with the distance; the higher the RSSI, the more distant the beacon is from the receiver.

The measurements are recorded from zero distance to 10 feet, at 2 feet intervals. At each 2 feet mark, the reading is measured over a duration of 15 seconds. Since the RSSI readings fluctuate, we record both min and max readings.

Figure 3 and Figure 4 illustrate the results for Bluetooth receiver from HTC and Samsung manufacturers.
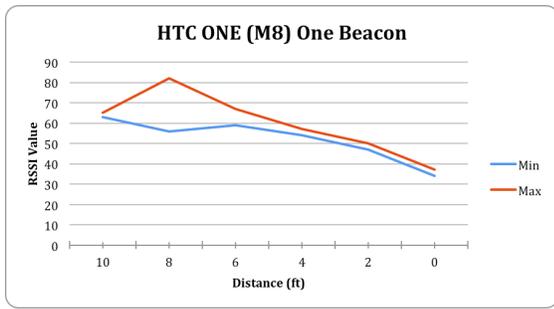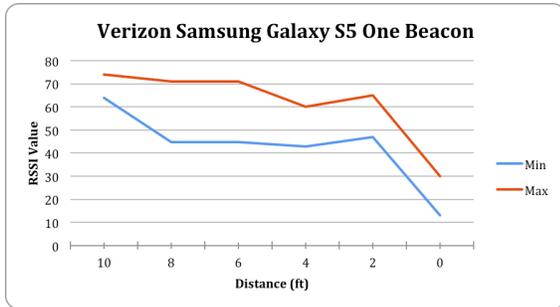
Figure 3: HTC - One Beacon Setup

Figure 4: Samsung - One Beacon Setup

3.2 Two-Beacon Installation

The two-beacon installation attempts to assess the signal interference impact of RSSI correlation. In this installation, we add a second Beacon perpendicular to the line between the Beacon and the receiver, and at a distance of 8 ft. Similarly, the readings are recorded over 15 seconds intervals.
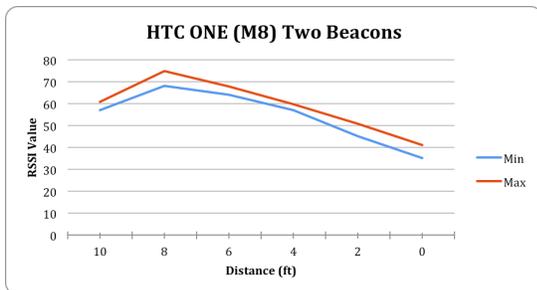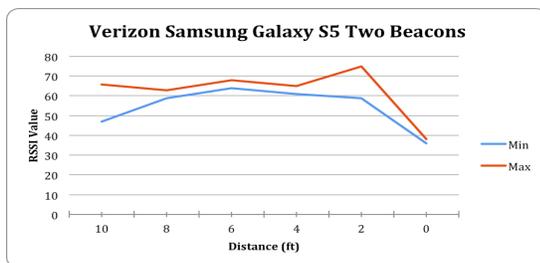

Figure 5: HTC Two Beacons Setup

Figure 6: HTC Two Beacon Setup

3.3 Three-Beacon Installation

We repeat the same experiment, with the addition of a third beacon placed perpendicular to the line between the first beacon and the receiver, and at a distance of 8 ft. The purpose is to measure the effects of signal interference when three beacons are present.
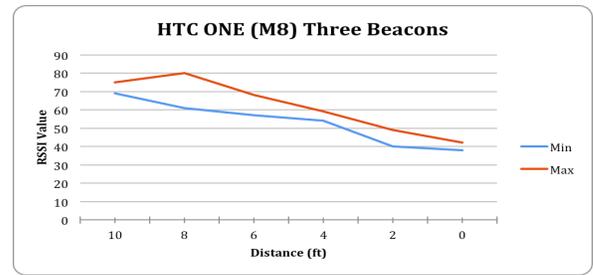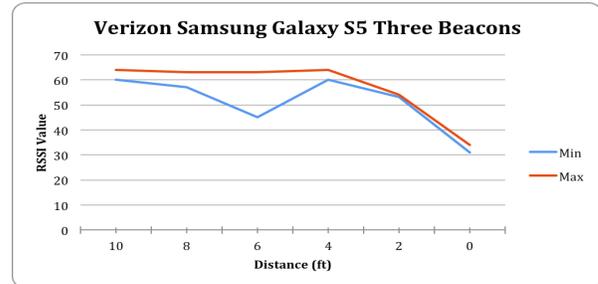

Figure 7: HTC Three Beacon Setup

Figure 8: Samsung Three Beacon Setup

3.4 Results Analysis

For effective localization, it is desired to find a consistent slope, reflecting a decrease in RSSI as the distance decreases. Over the three different installations, none of the manufacturers exhibited the desired slope. Moreover, results show that the presence of more beacons has a negative effect on the presence of the slope – thus, the more beacons, the weaker the correlation.

We note, however, that in all set-ups, RSSI values (both min and max) are lower at zero ft. distance than at >8 ft. distance. However, for our problem statement, 8 ft. accuracy range is insufficient for the fine-grained measurements requirements.

4. PROPOSED PROXIMITY DETECTION APPROACH

We propose a proximity detection system to overcome the limitations of current RSSI sensitivity. The approach relies on triangulation of RSSI from up to three beacons. Each beacon's reading will be classified as either *"Near"*, *"Far"* or *"N/A"*.

For example, in the floor plan shown in Figure 2, if the care provider is in Examination room II, the RSSI readings for that room will be "Near", and both beacons in Room I and II will have a *"Far"* reading. Such triangulation can overcome some of the limitations of signal interference.

However, with the existence of many more beacons and receivers, it is possible that such an approach is limited to only small size deployments. To support larger deployments, multiple wearables types may be required. For example, a smart door lock can identify incidents of door-open and door-closed events. Such data can be correlated with Bluetooth beacons information to enhance system accuracy. Similarly, a smart sanitizer or a smart water tab can communicate incidents of utilization. An activity tracker can monitor physicians moving status. If the physician is with the patient, then the tracker should be reporting stationary status. If the physician is walking to and from office, then the tracker should report moving status.

5. RELATED WORK

The challenge of performance management in the face of absence of granular data is recognized [13][14]. The potential for wearable applications to aid in clinical activities performance management has been investigated. The potential has been demonstrated in reducing cost [1][2], improving patients' outcomes [3], and improving care delivery [5][4][15].

Precision limitations of Bluetooth signals for indoors localization has been reported and empirically evaluated. In a study, researcher reported unsuitability of Bluetooth technology with commodity devices for indoor location mapping. This is despite the benefits of Bluetooth low power consumption and cost [10].

Soh has conducted an extensive study of Bluetooth signal parameters for indoor localization [12]. He also concludes that RSSI is a poor candidate for distance-based localization. However, Soh proposes "Received Power Level" as a candidate for correlation with distance.

Rodriguez, Pece, and Escudero developed an in-building system that uses static beacons to triangulate a user's position in a room [11]. They used the system to calculate a user's position within a 40 square meter space. They found this was accurate up to at best a 10% error and at worse a 45% error using 3 beacons when triangulating a user's position to a $1.25m^2$ segment of the room.

Different triangulation methods have been proposed Silke, et al proposed a triangulation method combined with least square estimation to predict the position of the receiver in a variety of indoor scenarios [1]. Their approach results in an accuracy of 8 meter on average.

Chang et al. have developed a system that uses Bluetooth in a location aware multicasting protocol [7]. This approach relies on a Bluetooth network that uses static Bluetooth beacons to communicate with a mobile beacon. The Chang el al report on interference between beacons and location mapping and propose a protocol to minimize this interference. To enhance localization accuracy, Lauri et al. utilizes Bluetooth with WAP to enhance accuracy [8]. They proposed a system that facilitates direct marketing based on customers' location.

Bluetooth based localization has been shown to facilitate the creation and sustenance of spontaneous Bluetooth networks. Gonzalez-Castano and Garcia-Reinoso [9] used bluetooth to spontaneously create the network and both transmit and receive data based on a users' location.

6. CONCLUSION

Healthcare is a domain that is in dire need of practical and timely performance management systems. Key challenges in healthcare institution include high level of variability and lack of fine-grained and timely data points. Portable technologies present a significant opportunity for providing fine-grained data for performance management. Adoption of such wearable technologies remains limited due to key limitations.

In this paper, we presented key system requirements for performance management and compliance developed in collaboration with a large community hospital in North America. We then presented an empirical evaluation of signal strength in varied beacon setups, as a means to address indoor localization problems related to portable technologies. The investigation demonstrated current limitations in beacon technology, which we propose to solve with a novel proximity-detection approach that relies on multiple wearables to triangulate signal data in an attempt to solve the localization problem. This approach could provide the detailed and reliable data needed for successful performance management and compliance in today's healthcare organizations.

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