Tortorella and Kinshuk *Smart Learning Environments* (2017) 4:4
DOI 10.1186/s40561-017-0043-9

Smart Learning Environments

RESEARCH Open Access

A mobile context-aware medical training system for the reduction of pathogen transmission

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Abstract

Even with the adoption of modern technology within the medical system, the spread of deadly pathogens remains a silent, yet deadly killer. Indeed, e-health, and in particular m-health is at the forefront of the computing portion of modern medical care. It follows the ubiquity of mobile computing devices that has become synonymous with modern life. Although the focus of m-health is patient based, this paper attempts to provide a focus on the healthcare service provider in an attempt to reduce the fatalities due to pathogen transmissions in care facilities. This paper proposes, and describes the creation and evaluation of an AI based context-aware mobile learning system designed to provide real-time training and support for medical cleaning staff. This learning system aims to bridge the gap between context-aware learning systems and m-health. As such, the system provides context information to the learner about the various threats and best ways to deal with possible pathogens in a long-term care scenario. The evaluation, field tested within the adult long-term care system demonstrates the benefit and validity of the system in both training and ongoing usage within the medical system.

Keywords: Context-aware learning system, Mobile learning, M-health, Ubiquitous learning, Long-term care

Introduction

Today, mobile computing devices are ubiquitous, and are found in every facet of life. This union between computing and our everyday world is not limited to our daily lives. The medical field is equally affected, where care is provided in a wide range of locations and situations. As such, there are two facets to the union of computing and the health care systems, namely e-health and m-health. E-health can be defined as any electronic exchange of healthcare related information across organizations (Deluca and Enmark, 2000). On the other hand, the more specific component of e-health called mobile health, or m-health is healthcare facilitated by the union of mobile and desktop healthcare with mobile wireless technology (Yu et al., 2006). M-health has garnished worldwide usage with its high reach and low cost solutions (Akter and Ray, 2010).

The medical field is constantly being flooded with new types of technologies, including context-aware systems and applications (Immanuel and Raj, 2015). Indeed, context-aware devices provide a natural fit into the world of m-health, providing sensor data based on patient information. Recent health care focus within context-aware m-health has been primarily on ICT, with attention being given to patient–centered care and monitoring (Broens et al., 2007) (Pawar et al., 2009). This type of context-aware care often directly involves the patient, such as in a recent study involving the long-term care requirements for diabetic patients, and the detection of abnormal blood-glucose level (Chang et al., 2016).

This attention to the context of the end user is by no means new to the computing field. In 1994 Schilit, Adams, and Want (1994) described a system which analysed and reacted to a person's changing context, including their location. Similarly, the union between learning and mobile technology is also developing, and growing as a phenomenon (Alrasheedi and Capretz, 2013). Mobile learning, as the name suggests is learning utilizing mobile technology, which takes into account the ubiquitous use of personal and shared technology. It must focus not on the learners or their technology, but the interaction between them to advancing their knowledge (Sharples et al., 2010).

However, although both m-learning and context-aware research show growing interest in their fields, there has been little research done involving the training of healthcare professionals using context-aware m-health systems. This paper seeks to help fill that void and proposes, creates and evaluates a system which combines context-aware aspect of the m-health with m-learning. The result is a device which provides real-time, context-aware medical training.

The proposed system provides real-time information about the potential risks and contamination issues of pathogens given the context of the learner and hence the medical environment in which they are situated. The system was designed with cleaning staff and medical professionals in mind: where it can be used not only as a training tool, but as a means for constantly reminding care staff about the risk of pathogen transmission.

The next section describes the rational and theoretical background, leading to the research question addressed in this paper. The subsequent sections address the creation and testing of the system, named as the Pathogen OutbReak PreventiOn Instruction SystEm (PORPOISE). The final section addresses the conclusions of this study and possible future direction of research.

Background and research question

The union of computer science and the medical field is an ongoing partnership, with recent research focusing on the utilization of computing to aid in training within the medical industry. For example, in a recent paper, Kanehira, Hori, Kawaguchi, & Fujimoto (2015) proposed a medical training system for the operation and troubleshooting of a heart-lung machine. In the same year, Mathur (2015) proposed a low cost virtual reality based medical trainer. Similarly in 2016, Lima et al. (2016) described an environment in which a 3D virtual reality game was used to help with the training of medical students in the identification of diseases in patients.

However medical computing interactions are not limited to training. Context-aware systems have also been used to help the medical community, by providing real-time context information to better assist medical staff. Kumar (2015) proposed a context-aware system which adapted to, amongst other things, the user's location and profile. The resulting system demonstrated a reliable solution for service selection when dispatching doctors to a medical emergency scenario. However, doctor routing in a hospital is certainly not the only usage of context-aware systems in a hospital environment. In 2015, Immanuel & Raj (2015) applied context aware computing to assist medical staff with necessary information for easy and critical time saving decision making when considering patient care.

Context of the patient also plays a significant role in the merger of computing and medical fields. Even with the modern leaps and bounds of technology development, sensor and device power-efficiency and miniaturization are an ever-present concern (Ghasemzadeh and Shirazi, 2013). Ghasemzadeh and Shirazi demonstrated that power consumption problems in medical devices could be reduced by integrating the context of the user in terms of location and activity. Similarly, when designing a system for the remote and real-time edema monitoring of patients, Fallahzadeh, Ma & Ghasemzadeh (2016) concluded that it was essential to monitor reliable context information. This context information was obtained via a context-aware body swelling identification system worn by the patient. Therefore, as seen in the aforementioned edema remote monitoring system, medical care is not limited to the confines of a hospital environment.

Long term care facilities often house the weak, elderly and terminal patients. Consequently, the spread of pathogens in such an environment can have deadly consequences. With an ever increasing and aging population in the western world, the need and usage of long term care facilities is escalating. According to the United States of America Center for Disease Control, as of 2014, there were 15,600 nursing homes, taking care of 1.7 million residents. These numbers result in approximately 2 million infections a year (Montoya and Mody, 2011). As such, proper training for cleaning staff at these facilities is of vital importance to the health and wellbeing of the residents. With an overall aging population, the number of residents and therefore of infections will only increase as well.

With an ever-increasing number of elderly people being confined to long term care facilities, how can their care be improved to help in the reduction of pathogen contamination? Can a system be developed which will adapt to the context of the learner, providing specific training on how best to aid in the prevention of the spread of potentially deadly pathogens? Achieved by merging the context-aware and training aspects of medical computing, the purpose of this research is to answer that question. To this end, a medical context aware mobile training system, namely PORPOISE (Pathogen OutbReak PreventiOn Instruction SystEm) has been developed.

PORPOISE is a prototype training system which provides context aware education to the learner: long term care facilities cleaning staff. The system adapts to both the environmental and locational context of the learner in order to provide training on the possible sources of infection, and the ideal way to eliminate help and reduce the spread of any potential pathogens. The conventional approach is to clean surfaces using common cleaning solutions, and to use specific cleaning solutions when an outbreak has been detected. The prototype provides a means to help train cleaning staff into proactive and accurate usage of cleaning tools preventing outbreaks from occurring.

The prototype has been tested by a team of support managers of long term care facilities. Various scenarios were presented to them along with a sample patient room layout (comprised of a bathroom and bedroom). Managers were given the system and evaluated its performance and potential education benefit to staff, and overall benefit to the industry.

Although research is available in the literature regarding the effects on pathogen contamination reduction via improved cleaning methods (Munoz-Price et al., 2012), scant research has been done focusing on the training based around non-medical care of patients. Even less attention has been paid to incorporate context-aware systems into training in an attempt to reduce pathogen transmission. In order to fill this gap in current research, the following section describes the architecture of the PORPOISE system, followed by the hardware overview. The final section will include an evaluation and future direction of where this research may proceed.

System architecture

The PORPOISE system is designed to provide medical training information to the end-user/learner on the spread of potential pathogens present within the system's proximate environment. In order to achieve this adaptation, the system must first analyse its surroundings (context) via its suite of sensors. Once the sensors have determined the context in which it finds itself, the system then adapts automatically (without any user involvement) to its surroundings. The adaptation is a determination and formulation of the various pathogens that may be present given the environmental conditions. Finally, based on this adaptation, the system provides pertinent training information to the end-user/learner via one or more of its displays. The system has been configured in order to achieve adaption to the learner's context, and is divided into three groups: System Setup Group, Decision Mechanism Group and the Input and Output Group (Fig. 1).

The system setup group is responsible for the correlations of sensor input to values needed for the inference engine. The decision mechanism group is made up of an inference engine and actions based upon rules, and is responsible for providing the correct

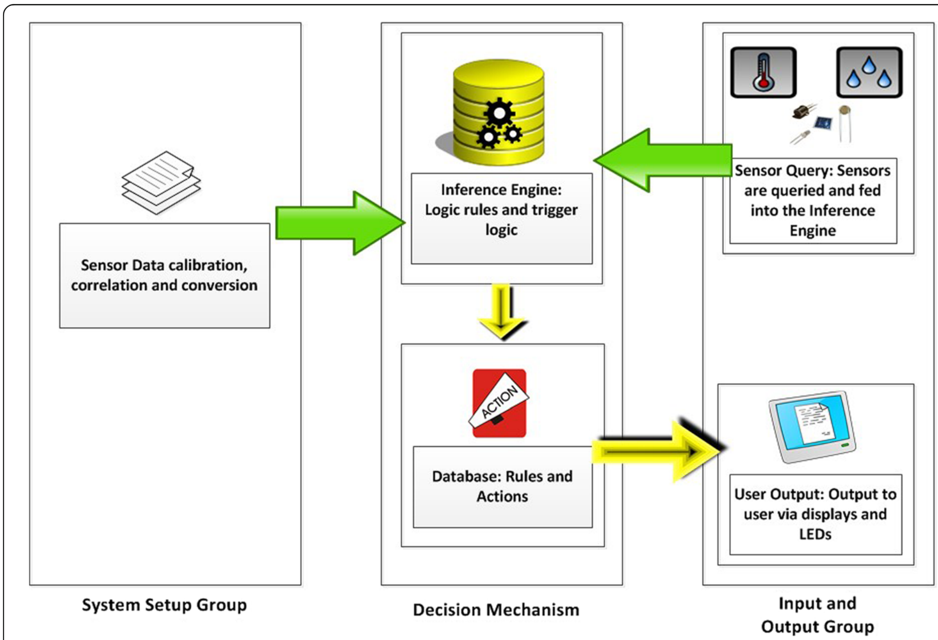

Fig. 1 System Architecture

information to the learner based on the context. Finally, the input and output group is responsible for handing the sensor querying process and provides information to the learner via various LED displays. The three groups will be discussed further in the next sections.

System setup group

The system setup group is responsible for the translation and correlation of various types of sensor data into a format that is understandable by the decision mechanism. This involves processing the raw sensor data, which may be in a number of formats (such as voltage or resistance) and converting it into a usable configuration.

PORPOISE uses several types of sensors to determine the environmental context:

- Location
- Temperature
- Humidity
- Pressure
- Date

Each of these data values need to be coded into a meaningful fashion that is able to be used by the decision mechanism.

Decision mechanism

The decision mechanism on the PORPOISE is at the heart of the system's adaptation and includes an inference engine and a database. In the inference engine are a set of rules which trigger the various types of user output given particular conditions from the environmental sensors. The database is a means to store the rules and actions that may be triggered by the varying sensor status.

In order to achieve accurate medical information with which to program PORPOISE, long term care industry experts, medical professionals, along with the local center for disease control (CDC) were consulted. This was done in order to obtain accurate information on the relation to environmental data, and best industry practices of pathogen prevention, both in terms of environmental factors, but also cleaning.

The inference engine was therefore programmed with a multitude of rules which indicated the likelihood of a particular pathogen provided any given set of environmental and locational conditions. As it is was not possible to provide it for all known pathogens, the top 10 pathogens were entered as possible sources of infection as is found in most long term care facilities in North America. Although the rules themselves are coded into programming statements, the general setup of the rules seek to check for the various conditions for different pathogens. For example, the conditions of two common pathogens are as follows.

Type a influenza

- Dates Range: December to March and October to May
- Temperature Range: Less than 30C ambient air temperature
- Relative Humidity Range: Rapid onset found less than 30% RH

- Key areas and Location: Door knobs, countertops and discarded personal hygiene products
- Area of Interest: Bathroom and Bedrooms
- Recommended Cleaning Agent: 1:10 - Bleach Solution

Rotavirus/gastroenteritis

- Dates Range: October to March
- Temperature Range: 20C
- Relative Humidity Range: caution range 50% RH
- Key areas and Location: bathroom and toilet
- Area of Interest: Bathroom
- Ideal Cleaning Agent: Oasis 499

Modern technology still does not permit direct quick detection of pathogens. Therefore indirect detection of the various conditions which support said pathogens is utilized. Additionally, the training of the optimal location and method of prevention/eradication of the pathogen is provided as a tool of the system. These various interactions and analysis of the environment is handled via the input and output groups of the system.

Input and output group

This grouping is responsible for the physical way the system both detects (input) the world and interacts with the learner (output). The system's input is a series of sensors of varying kinds which are constantly being monitored, their output being relayed back to the decision mechanism. Once the decision mechanism has analysed the sensor information and determined which rule to enact, any type of output to the learner is handled by the output group. The output group is responsible for maintaining the various LCD screen and information LEDs of the system in a suitable manner.

Hardware overview

In order to further understand the PORPOISE system, an overview of the various hardware components is required. PORPOISE is divided into two main hardware components, the main processing handheld unit, and the Wi-Fi location beacons. The main processing unit is the handheld device which contains the user interface, decision mechanism and the sensors. The Wi-Fi location beacons are self-contained devices used to provide spatial location to the main processing unit. The following sections describe the hardware in further detail.

Main processing handheld unit

This section describes the main user system, containing the primary components of the PORPOISE system. The main processing handheld unit (Fig. 2) contains the decisions mechanism, user interfaces and system sensors. The system's enclosure is a custom made 3D–printed setup designed to house the various components and sensors. The heart of the system is a Raspberry Pi 3 (RPi3), equipped with a wireless network interface adapter used to detect the Wi-Fi locator beacons. The sensor bay houses the

Fig. 2 Main Processing Handheld Unit

environmental sensors and includes an induction fan to ensure that adequate sampling of ambient air is constantly being monitored. The user interface is comprised of a set of two LCD displays and an OLED display and a Status LED. The three displays are used to provide the learner with training information based on the context and location of the device. The status LED is used to warn the learner of potential patient threats obtained from the location of the device.

Raspberry Pi setup

As mentioned above, the heart of the system is the Raspberry Pi. The reasons this was selected as the main processor of the system, include specifications, GPIO and storage.

Specifications

The specifications of the Raspberry Pi 3 (RPi3) are formidable given its small footprint. It comes equipped with a quad-core 1.2GHz ARM Cortex A53. Additionally, although a third party USB wireless adapter was used, the RPi3 does come equipped with an internal onboard Wi-Fi adapter as well as onboard Bluetooth adapter for additional interfaces as needed. Following industry trends, the RPi3 comes with a built-in Network Interface Card (NIC), four USB ports and audio outputs. These outputs permit for numerous possible upgrades in future revisions. However none can be as powerful as the General Purpose Input/Output (GPIO) pins.

GPIO

The strong point of the RPi lineup is that of the 40 GPIO pins. This allows for a multitude of various direct sensor connection as well as being able to utilize standard buses such as the Inter-Integrated-Circuit (I2C) and the Serial Peripheral Interface (SPI).

Storage

The final major advantage of the RPi platform is the storage capabilities. The PORPOISE system utilized a 8GB storage card, containing the operating system (Raspbian) as well as the system code and database. However additional storage can be used of up to 64GB (and possibly beyond) if needed. This would allow for additional expandability and programming of the system.

Sensor bay

This component houses the environmental sensors of the device. It is outside of the main body of the device to ensure that the varying thermal and environmental effects from the device itself are negated as much as possible. Furthermore, the external position of the sensor bay allows for the attachment of an induction fan. The induction fan is a key aspect to the sensor system since it draws ambient air over the sensors, ensuring a correct sampling of the existing ambient air. The sensors in the sensor bay are powered by a 3.3 V power rail, and connected to the central processing unit (Raspberry Pi) over the system's I2C bus.

LED and OLED displays

These are the three means by which the system can display written information to the learner. The LCD displays are 20 X 4 displays hooked up over the system's I2C bus. These are responsible for the instructions, warnings and information passed onto the learner. The OLED display, also on the I2C bus, provides the learner with a scrolling real-time feed from all the sensors. The OLED serves as both a learning aid and as a diagnostics information panel if needed. Given their relative high power requirements, the various LCDs are powered by an independent 5 V power rail.

Status LED

The Status LED on the system is a simple RGB LED, which changes colour depending on the location of the user. It is designed to warn the learner/caregiver of the potential hazards originating from the patients at a care facility. The color scheme is coded from the local health care authority as industry indicators for patient's threat level to caregivers. For example, a purple/violet colour is an indication of a possible violent patient; whereas a green colour indicates that no/minimal threat level is present.

Power level indicators

The power level indications help to determine the remaining runtime of a unit. If the unit is less than 10% batter life, the status LED flashes red, and if outside of a resident's living space, a small buzzer is sounded.

Data port

The system needs updates to its database in order to deal with the constant movement of patients within a facility. Therefore, a data port is provided to allow for such updates as required.

Wi-Fi locator beacons

The other main component to the PORPOISE, in addition to the main handheld unit, include the Wi-Fi locator beacons. In order to detect the indoor location of the device, and thus the learner, a method was needed for accurate spatial location. Given the typical concrete nature of the medical facilities, global positioning systems were not a possibility, as their signal could not penetrate the interior of the building with any degree of reliability. A solution was needed that was not only easy to implement, but also provided an accurate location for the device. Figure 3 shows the solution to the indoor location problem: a Wi-Fi beacon. The Wi-Fi beacon is comprised of an ESP-8266, and lithium polymer power source. The ESP8266 is a low-cost micro controller with a Wi-Fi chip with full TCP/IP stack. For the beacon purposes, the ESP8266 was designed to broadcast an SSID (shown in Fig. 3 as different coloured circles for each SSID) as an access point. The name of the access point would indicate the room and location (bedroom or bathroom). The handheld unit then cross references the name of the closest Wi-Fi beacon (determined by signal strength) and can call up both patient information and additional factors.

As shown in Fig. 3, careful placement of beacons on the ceiling 1.5 m from every door ensures the most powerful Wi-Fi signal received by the handheld unit will always be the beacon corresponding to closest room. Each coloured beacon represented the same room, thus in Fig. 3, we see two beacons representing the bedroom, and one representing the bathroom. In rooms with greater expanses than expected, numerous beacons can be placed within the room. The naming convention of the various SSIDs was as follows:

- *SITE-RoomNumber-Location*
- *SITE*: Represented the various building site code.
- *RoomNumber*: The room number often in format: Room XXX
- *Location*: The differentiation between various ancillary rooms.
- For example, the testing beacons were: WC01-Room101-Main and WC01-Room101-WR

The following section addresses the means by which the above system was evaluated and the resulting findings of said evaluation. The system was evaluated on how well it is able to provide specific training on how to aid in the prevention of the spread of potentially deadly pathogens. Additionally, the systems' overall suitability and user friendliness is evaluated using the system usability scale.

Evaluation

Part of the proper creation of any system is some type of independent evaluation, the same is true for the PORPOISE system. However, given the rather diverse circumstances

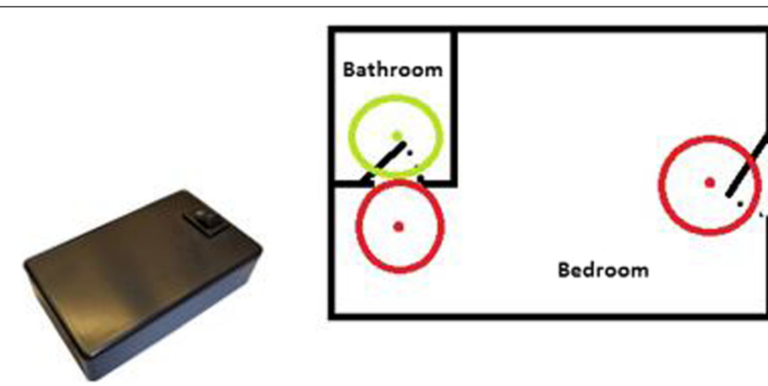

Fig. 3 Wi-Fi Beacon

in which the system should be tested, the question of whether to do field tests/trials vs lab tests with participants was addressed. In order to do field tests, the biggest issue is the ability to have the system in varying contexts over the duration of the testing. As the context varies day to day and season to season, the testing and evaluation of the system would need to be run over the course of months if not years. The decision was therefore made in support of laboratory testing, as per (Kjeldskov et al., 2004) testing a context-aware mobile system under controlled settings does not decrease the ability of the evaluation to detect usability issues vs. real world testing. Therefore the test was conducted in a training scenario with the participants having access to a simulated environment where the sensors were fed hypothetical contextual information. Although the location detection was done using actual sensor data, the varying date and environmental conditions were simulated, using conditions that may be found over the course of a year in the field.

During the 4-h demonstration and testing window, the prototype system reacted in exactly the same way it would if the sensors themselves were providing the information – giving the participants the exact same style and feedback found in the real world. The system was however then put into "live" mode, where the system interacted with the actual environmental context, giving an indication of how the system adapted to the training room facility and what information was given to the learner.

In total 16 participants participated in the study, overseeing over 500 healthcare cleaning professionals. Each participants was demonstrated the usage of the system and was given the opportunity to test the device.

In order to accurately judge the usability of the device, several questionnaires were reviewed and the System Usability Scale (SUS) (Brooke, 1996) was decided upon as being the most effective means of testing. The questions from the SUS (one through ten) were slightly modified to better represent the system under consideration. Additionally, two questions (numbered eleven and twelve) were added directly addressing the training potential of the device.

The questions were as follows (Table 1):

Table 1 Questionnaire Results

Question	Average Scale Value (0–4)
1. I think my staff and I would like to use this system frequently	3.3
2. I found the system unnecessarily complex	0.9
3. I thought the system was easy to use	3.4
4. I think that my staff and I, would need the support of a technical person to be able to use this system once it has been setup for my site	2.2
5. I found the various functions of this system were well integrated	3.4
6. I thought there was too much inconsistency in this system	0.8
7. I would imagine that most of my staff would learn to use this system very quickly	3.4
8. I found the system very cumbersome to use	0.7
9. I felt very confident using the system, and that it provided useful information	3.6
10. My staff and I will need to learn a lot of things before we could get going with this system	1.5
11. My staff would benefit from using this system	3.6
12. This would serve as a good training/reminder tool	3.7

Each of the questions used a 0–4 Likert scale for their response, with 0 corresponding to strongly disagree and 4 with strongly agree. The questions were administered after the participants had an opportunity to use and see the PORPOISE system being evaluated, but before any form of discussion took place.

After the administration of the questionnaire, an informal discussion took place to gauge the overall feeling for the PORPOISE device.

Results

The first ten questions were scored in a similar fashion to the SUS score. Each question ranged from zero to four. For odd numbered questions, the contribution to the total is the Scale Position minus 1, and for even numbered, it is 5 minus the scale position. Factoring in the mean scores for each of the first 10 questions, the SUS scoring results in a 90.6. According to (Bangor et al., 2009) the ratings equate to an adjective rating of "Best Imaginable".

For the last two questions, although not part of the original SUS questionnaire, the outcome was to overtly ask the participants to rate the product, not on usability, but overall quality to achieve the intended outcome: the system's training potential to aid in the prevention of the spread of potentially deadly pathogens. The mean values were 3.6 out of 4 for question 11, and 3.7 out of 4 for question 12. These answers, along with SUS results and post discussion indicate a very positive outcome and well received prototype.

The general discussion after the questionnaire was administered was once again very positive, with a perceivable deal of excitement of using the device within the various sites and locations from the managers.

Conclusions

In this paper a system has been proposed, created and tested of a context-aware learning system for the healthcare sector. The resulting system, called PORPOISE, incorporates the adaptation of context information based upon the system's (and hence the learner's) environment with pertinent medical training and information. The focus of the training involves the prevention of the spread and outbreak of pathogens in a long-term care facility. Such facilities are designed to meet the needs for individuals who due to chronic illness, age or disability are unable to care for themselves.

The PORPOISE system was tested in situ under controlled conditions with healthcare managers for a large long-term care support service company as participants and evaluators. The participants were given the opportunity to test and evaluate the system. The evaluation was comprised of the system usability scale, as well as two training potential questions. The results were very positive both in the system's usability but also the general training potential feedback.

Within the population sample being represented, the PORPOISE device, and thus the underlying concept of context-aware mobile learning in the medical field was a success. Although this device was a prototype proof of concept, it is the hope that future work may build upon this and help train our medical service professionals to help some of the most vulnerable and needy members of our society.

Acknowledgements
Not Applicable.

Funding
No sources of funding present.

Availability of data and materials
Data is provided within the manuscript.

Authors' contributions
The authors RT and K were both involved in every aspect of the research presented. All authors read and approved the final manuscript.

Ethics approval and consent to participate
No ethical approval was required for the testing of the prototype presented in this research.

Consent for publication
Not Applicable.

Competing interests
The authors declare that they have no competing interests.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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Received: 30 June 2017 Accepted: 22 September 2017
Published online: 04 October 2017

References

Akter, S, & Ray, P (2010). mHealth-an ultimate platform to serve the unserved. *Yearbook of Medical Informatics*, 94–100.

Alrasheedi, M, & Capretz, LF (2013). *Teaching, Assessment and Learning for Engineering (TALE), 2013 IEEE International Conference on*. IEEE.

Bangor, A, Kortum, P, Miller, J (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of Usability Studies, 4*(3), 114–123.

Broens, T, Van Halteren, A, Van Sinderen, M, Wac, K (2007). Towards an application framework for context-aware m-health applications. *International Journal of Internet Protocol Technology, 2*(2), 109–116.

Brooke, J (1996). SUS-A quick and dirty usability scale. *Usability Evaluation in Industry, 189*(194), 4–7.

Chang, S-H, Chiang, R-D, Wu, S-J, Chang, W-T (2016). A Context-Aware, Interactive M-Health System for Diabetics. *IT Professional, 18*(3), 14–22.

Deluca, JM, & Enmark, R (2000). E-health: the changing model of healthcare. *Frontiers of Health Services Management, 17*(1), 3.

Fallahzadeh, R, Ma, Y, Ghasemzadeh, H (2016). Context-Aware System Design for Remote Health Monitoring: An Application to Continuous Edema Assessment. *IEEE Transactions on Mobile Computing*, (99), 1–1.

Ghasemzadeh, H, & Shirazi, B (2013). *2013 IEEE Global Conference on Signal and Information Processing*.

Immanuel, VA, & Raj, P (2015). *2015 International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT)*. IEEE.

Kanehira, R, Hori, H, Kawaguchi, K, Fujimoto, H (2015). *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*.

Kjeldskov, J, Skov, MB, Als, BS, Høegh, RT (2004). 'Is It Worth the Hassle? Exploring the Added Value of Evaluating the Usability of Context-Aware Mobile Systems in the Field'. In Brewster, S. and Dunlop, M. (Eds.), *Mobile Human-Computer Interaction - MobileHCI 2004: 6th International Symposium, MobileHCI, Glasgow, UK, September 13–16, 2004* (pp. 61–73). Proceedings. Berlin, Heidelberg: Springer Berlin Heidelberg.

Kumar, BA (2015). *2015 1st International Conference on Next Generation Computing Technologies (NGCT)*.

Lima, RMd, Santos, AdM, Neto, FMM, Neto, AFdS, Leão, FCP, Macedo, FTd, Canuto, AMdP (2016). *2016 IEEE International Conference on Serious Games and Applications for Health (SeGAH)*.

Mathur, AS (2015). *2015 IEEE Virtual Reality (VR)*.

Montoya, A, & Mody, L (2011). Common infections in nursing homes: a review of current issues and challenges. *Aging Health, 7*(6), 889–899.

Munoz-Price, LS, Birnbach, DJ, Lubarsky, DA, Arheart, KL, Fajardo-Aquino, Y, Rosalsky, M, Cleary, T, DePascale, D, Coro, G, Namias, N, Carling, P (2012). Decreasing Operating Room Environmental Pathogen Contamination through Improved Cleaning Practice. *Infection Control & Hospital Epidemiology, 33*(9), 897–904.

Pawar, P, van Beijnum, B-J, Mei, H, Hermens, H (2009). Wireless Pervasive Computing, 2009. ISWPC 2009. 4th International Symposium on. IEEE.

Schilit, B, Adams, N, Want, R (1994). 'Context-Aware Computing Applications. *First Workshop on Mobile Computing Systems and Applications*, 85–90.
Sharples, M, Taylor, J, Vavoula, G (2010). 'A theory of learning for the mobile age'. In *Medienbildung in neuen Kulturräumen* (87–99). Springer.
Yu, P, Wu, MX, Yu, H, Xiao, GQ (2006). *2006 IEEE International Conference on Service Operations and Logistics, and Informatics*. IEEE.