Development and Evaluation of a Non-obtrusive Patient Monitoring System with Smart Patient Beds

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Abstract. In Chinese hospitals, each patient is checked regularly during their night time. This happens to confirm that there are no emergency situations in which a patient is in need of immediate help. Because the regular checking can be very annoying for patients who are sleeping due to noise, we are looking for a solution to solve this problem using technology. The focus lies on non-obtrusive sensing technologies and on the social relation between patient and doctor. Two prototypes were developed, tested and evaluated on their usability to monitor patients from the central nurse station without disturbing them. The first prototype consists of a piezoelectric sensor with filtering circuit which measures the heartbeats. The second consists of a capacitive sensor capable of sensing the presence of a patient in the bed. Both sensors are placed under the mattress of the patient with as a result that they are not bothered while being monitored.

Keywords: Ballistocardiography · Capacitive proximity sensors · Monitoring · Patient-doctor relationship · Chinese hospitals

1 Introduction

In Chinese hospitals, there is a tension between patient and doctors [1, 2]. Patients experience long waiting lists, increasing out-of-pocket healthcare expenditure and the making of an appointment with a qualified doctor is difficult. That is the reason why patients want to make sure they receive good treatment once they are finally being treated. Due to this situation the patients raised awareness about their protective rights. However, the patients are lacking knowledge about the medical specialism of the doctors. On the other side the doctors are not satisfied with their jobs due to low income, long working hours and the feeling that they are not appreciated by the patients and society. But the management in Chinese hospitals is not always professional. Rules and regulations cannot be executed strictly. The levels of professionality of the Chinese doctors vary. This results in the making of mistakes by lower skilled or experienced doctors causing the loss of trust of the patients in the Chinese doctors [3]. The tension

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between patient and doctor sometimes even results in violent conflicts [4]. Also it occurs that patients sue the hospital because they think they are not treated well. The Chinese hospitals want to avoid this. Therefore, there is a regulation in Chinese hospitals in which every patient has to be checked by a nurse regularly during the night, and normally the regular check happens every one hour or two hours. In this routine, the medical staff makes sure there are no emergency situations to avoid the blame in case a patient doesn't receive first aid in time. However, these actions can be annoying for the patients who are trying to sleep.

Except for the traditional regular checking solution, some other ways by using technology have been proposed as well. Zephyr BT is a kind of wearable sensor which can be used to extract the heart rate information of a patient [5]. Such kind of wearable sensors do satisfy the requirements of patient monitoring. However wearable devices reduce the comfort of sleeping based on the current applicable technology. Video Surveillance is another kind of popular solution, but the security and privacy concerns hinder the deployment [6]. Using Kinect Signature somehow improves the video surveillance solution technically [7]. The security and privacy concerns are not really overcome. Furthermore, the cost of the Kinect Signature is another weak point.

We turned this problem into a design opportunity to explore a low cost, non-disturbing and emotional secure solution. We wondered if non-obtrusive monitoring technology could be used to keep track of the patients heart rate and respiration, to make sure everything is OK without waking them in their night-time. In this way the hospital can provide better care for their patients and reduce the workload. This is what the Chinese hospitals are aiming for [8]. One important design challenge is the social part in this project: how to communicate to the patient that they are being monitored? The patient needs to have the feeling that he or she is taken care of and should trust the system. The method used in this design project is iterative design.

Related work includes the investigating of low-cost wireless occupancy sensors for beds [9]. In this research two solutions to sense presence of people in beds are compared: capacitive proximity sensors and accelerometers. Also the sleep trackers of the company Emfit are related to this project [10]. The company uses ballistocardiography as a method to sense heart beats [11] and calculate the BPM to tell the user something about their sleep quality. The sensor is placed under the mattress so there is no contact with the patient.

2 System Design

The designed system is a distributed system with interfaces [16, 17] on several heterogeneous platforms. The system consists of smart patient beds which are wirelessly connected to the computers at the nurse stations. The smart patient beds contain:

1. a piezoelectric sensor to measure the heart rate of the patient
2. a capacitive sensor to measure the presence of a patient in the bed
3. a feedback mechanism to communicate to the patient that he or she is being monitored (still to be designed)

The data from these sensors is sent wirelessly to the central nurse station. This information will be shown in the software which nurses are currently using. The nurses will receive a warning message on their desktop and mobile device when an abnormal situation is detected by the software e.g. the situation in which presence in the bed but no heartbeat is detected. In this way the nurses know when they should visit the patient and take action if needed (Fig. 1).

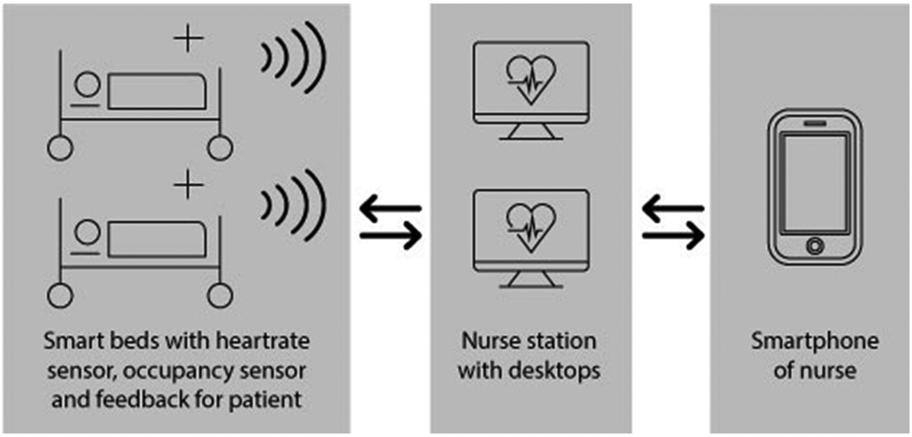

Fig. 1. Connection of smart devices in the system

2.1 Heart Rate Sensor

To measure the heartbeat of the patient lying in the bed the method ballistocardiography is used. In this method the ballistic forces of the heart are measured with a sensitive sensor which is able to capture the smallest vibrations. In this project the piezoelectric film of Emfit is used as the sensor. The sensor is placed under the mattress of the hospital bed. When the patient lies on the bed, the vibrations generated by his or her beating heart travel through the mattress to the piezoelectric sensor. At every heart beat the sensor is pressed very gently which generates a small voltage. This voltage can be measured with an Arduino Uno microcontroller by reading the input on the connected analog port.

Because the patient also makes other movements like breathing (small movements) and turning around (big movements) the signal needs to be filtered. This can be achieved with an electronic filtering circuit [12] and by filtering digitally. A prototype was designed to amplify the signal and filter frequencies below 1 Hz and higher than 5 Hz. Also a 16-bit Analog to Digital converter was added to the circuit in order to read the signal in a higher resolution. The components were soldered on perfboard in such a way that the board could be mounted on the Arduino Uno like a “shield” (Fig. 2).

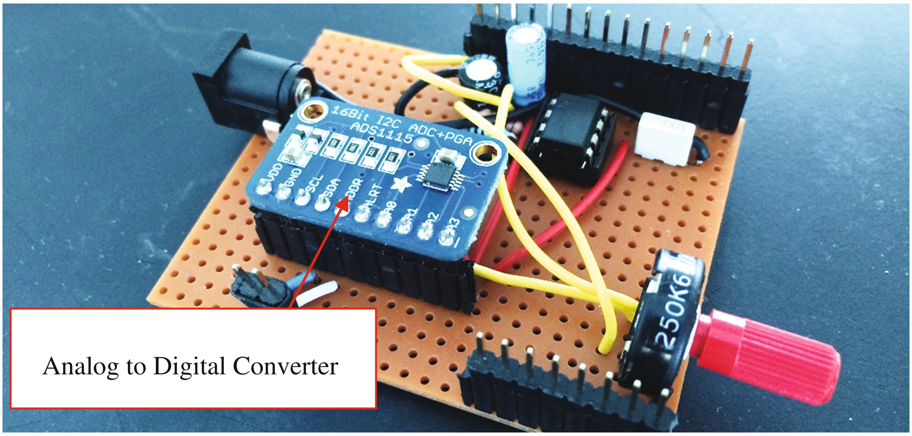

Fig. 2. Prototype shield for Arduino Uno containing filtering circuit and 16 Bit Analog to Digital Converter (ADC) for higher signal resolution.

2.2 Occupancy Sensor

In order to know if a patient is in the bed or outside the bed another sensor is needed. A possible situation is that the patient is in the bed but the heart has stopped beating. In this case the nurses can be warned. Like discussed we focus on non-obtrusive sensor technologies. Capacitive proximity sensing is a suitable technology in this situation. Like the piezoelectric sensor, it can be placed under the mattress. Because the human

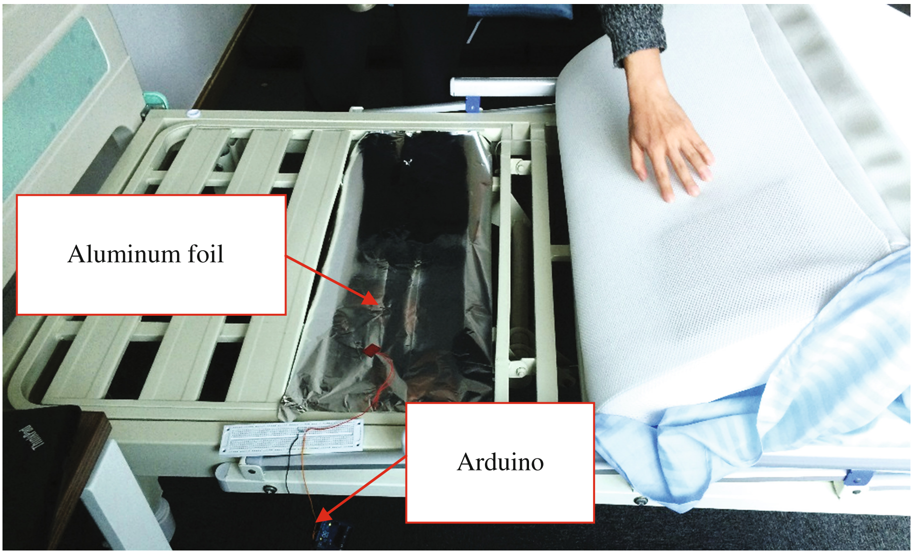

Fig. 3. Capacitive sensor experiment setup with aluminum foil over the full width of the hospital bed functioning as sensor.

body can hold an electrical charge, the presence of the human body in or near the bed can be sensed. There is no need for direct contact between the sensor and the human body. In this project aluminum foil is used as the capacitive sensor. A large surface was used for a bigger sensing range. The sensor was connected to a circuit with a resistor and to the analog port of the Arduino [13]. By playing with the resistor value the sensitivity of the sensor could be adapted (Fig. 3).

3 Evaluation

Both the heart rate sensor and capacitive sensor were tested and evaluated in the International SmartHealth Lab in Hangzhou. Also the heart rate sensor was demonstrated with real time output in The First Affiliated Hospital, Zhejiang University, Shengzhou Branch.

3.1 Heart Rate Sensor

The heart beat signal generated by the piezoelectric sensor was read with the Arduino. These values were visualized using a Processing code [14] which was developed for finger or ear pulse sensors. This code is also capable of calculating the BPM and IBI when using these sensors. Using the piezoelectric sensor without adapting the code will generate false values because the code is not calibrated for this sensor. But the plotted graph could show the typical heart peaks of a ballistocardiogram. Compared to a finger or ear sensor, the signal coming from a piezoelectric sensor contains more noise which has to be filtered. An algorithm designed to generate the BPM out of a signal coming from a piezoelectric sensor should be used instead. These algorithms already exist (Fig. 4).

The heart rate sensor was also demonstrated in The First Affiliated Hospital, Zhejiang University, Shengzhou Branch. The sensor was placed under the mattress of the hospital bed. The output was visualized using the built in Arduino serial plotter function. In this way the doctors could see the measured heat beats in real time. Also commercial sleep trackers with piezoelectric sensors with real time BPM were demonstrated. These trackers needed an interval of 10 s to calculate the BPM. A professional heart beat sensor from the hospital which uses the blood volume that flows through the fingertip as input was used to compare the two BPMs. The difference ranged from 0 to 5 beats. The hospital is interested in the technology but said the BPM needs to be more accurate before they would use such systems in their hospitals.

Because the piezoelectric sensor is so thin, a person lying on the bed does not feel the difference with the normal situation. Because there is no direct contact with the patient this solution is also hygienic (Fig. 5).

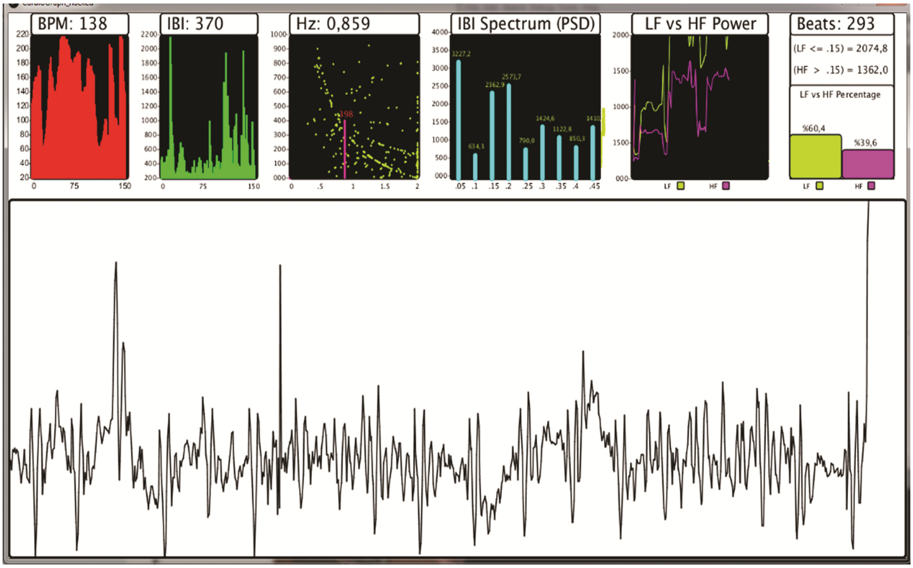

Fig. 4. Ballistocardiogram (BCG) of data processed by Arduino and visualized in Processing.

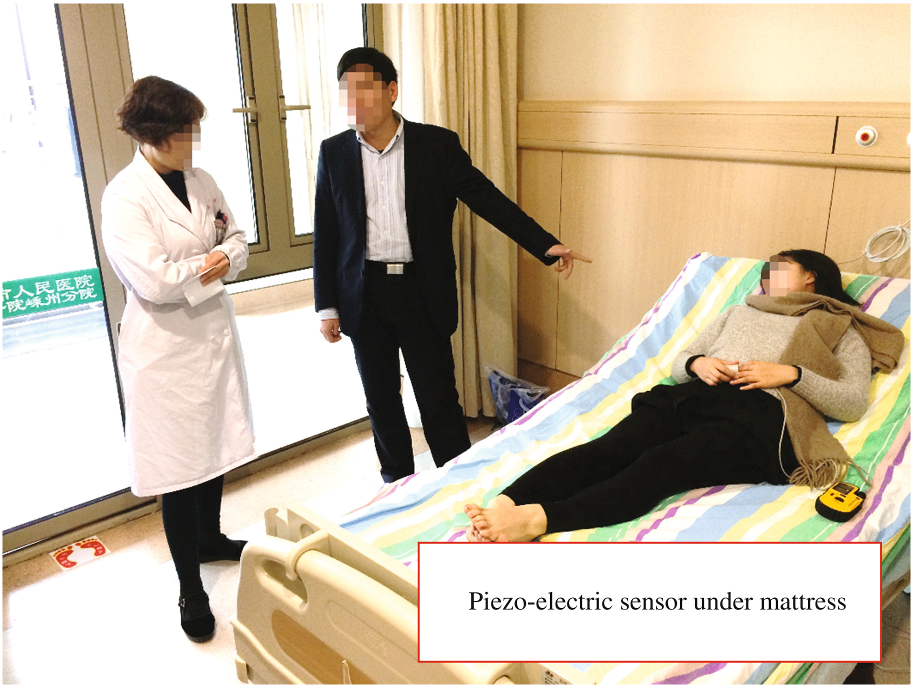

Fig. 5. The prototype is tested and demonstrated to the doctors in The First Affiliated Hospital, Zhejiang University, Shengzhou Branch.

3.2 Occupancy Sensor

The capacitive sensor was only tested in the laboratory and not demonstrated in the hospital yet. Like shown in Fig. 6, the presence of a human body could be sensed clearly. Because the experimental Arduino setup was connected with a USB-cable to the laptop, the laptop itself functioned as a sensor as well. What also has to be taken into account is the hospital bed itself, because it built from metal parts. This influences the capacitance. It is important to calibrate the sensor first when it is placed in the bed before putting a patient in the bed.

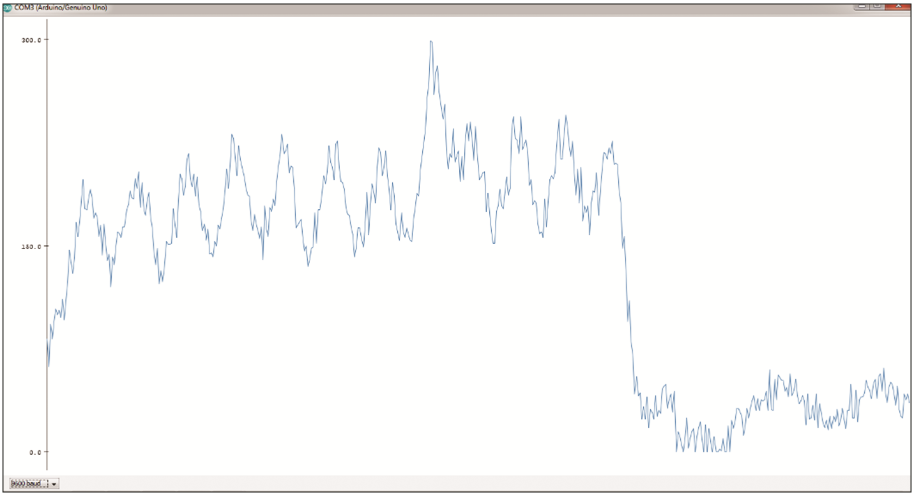

Fig. 6. Graph of capacitive sensor output made with Arduino serial plotter showing the difference between no presence of a person in the bed (left) and presence of a patient in the bed (right).

Instead of aluminum foil the next prototype could be made of a more durable material like copper foil, integrated together with the piezoelectric film. It needs a protective and strengthening layer of plastic and/or foam because it is easily folded.

4 Discussion

The combination of the piezoelectric sensor and the capacitive sensor is considered as an applicable solution for patient monitoring. Comparing with the inefficient regular checking, our solution provides a user-friendly way to reconstruct the relationship between nurses and patients. The nurses only visit and give help when the patients need help during the night time, without any redundant disturbing. In the meanwhile, the condition of the patients is monitored in real time and the nurses don't need to worry about the missing of any emergencies. Therefore, the responsibility of nurses is turned into the functionality of the monitoring system, it contributes to the improvement of the relationship between patients and nurses.

What still is missing is the feedback loop for the patient being monitored. The patients need to have the feeling that they are being monitored from a distance and trust that the nurses will visit them when they are in need of help. This could be a light or display next to the patients bed visualizing the sensed data e.g. in or out the bed, but this is just a simple example. The final solution for this situation still has to be designed and evaluated. The design will be evaluated with qualitative research by doing user test in which test subjects will lie in a hospital bed experiencing the feedback mechanism. After their experience they will be asked questions. Once a suitable design is found the design can be tested and evaluated in a pilot study in the hospital setting in China.

Like discussed in the chapter evaluation, the hospital is interested in the system. However, the demonstrated BPM calculating algorithm needs to be more accurate before they would use such systems in their hospitals. Qualified algorithms of BPM calculation already exist and are in practice. Future work includes the analysis and improvement of Heart Rate Variability (HRV)derived from BCG. Many diseases can be observed by analyzing HRV. In this case, the system could assist the nurses, especially to prevent critical situations. The same system or technology could also be used in retirement homes or used by elderly people living alone.

5 Conclusion

We presented and evaluated a non-obtrusive patient monitor system which could be used in Chinese hospitals. The system consists of a piezoelectric sensor to measure heart rate, a capacitive proximity sensor to measure presence of the patient in the bed and a feedback mechanism for the patient to communicate that they are being monitored. We conclude that ballistocardiography and capacitive proximity sensing are usable technologies to use in this context. The feedback mechanism still needs to be designed and evaluated in future work. Especially the effect on the patient-doctor relationship needs to be taken into account. “In the era of social networking and computing, things and people are more and more interconnected, giving rise to not only new opportunities but also new challenges in designing new products that are networked, and services that are adaptive to their human users and context aware in their physical and social environments” [15]. The effects on the social trust of this system is yet to be investigated.

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Foreword

The 19th International Conference on Human–Computer Interaction, HCI International 2017, was held in Vancouver, Canada, during July 9–14, 2017. The event incorporated the 15 conferences/thematic areas listed on the following page.

A total of 4,340 individuals from academia, research institutes, industry, and governmental agencies from 70 countries submitted contributions, and 1,228 papers have been included in the proceedings. These papers address the latest research and development efforts and highlight the human aspects of design and use of computing systems. The papers thoroughly cover the entire field of human–computer interaction, addressing major advances in knowledge and effective use of computers in a variety of application areas. The volumes constituting the full set of the conference proceedings are listed on the following pages.

I would like to thank the program board chairs and the members of the program boards of all thematic areas and affiliated conferences for their contribution to the highest scientific quality and the overall success of the HCI International 2017 conference.

This conference would not have been possible without the continuous and unwavering support and advice of the founder, Conference General Chair Emeritus and Conference Scientific Advisor Prof. Gavriel Salvendy. For his outstanding efforts, I would like to express my appreciation to the communications chair and editor of *HCI International News*, Dr. Abbas Moallem.

April 2017 Constantine Stephanidis

HCI International 2017 Thematic Areas and Affiliated Conferences

Thematic areas:

- Human–Computer Interaction (HCI 2017)
- Human Interface and the Management of Information (HIMI 2017)

Affiliated conferences:

- 17th International Conference on Engineering Psychology and Cognitive Ergonomics (EPCE 2017)
- 11th International Conference on Universal Access in Human–Computer Interaction (UAHCI 2017)
- 9th International Conference on Virtual, Augmented and Mixed Reality (VAMR 2017)
- 9th International Conference on Cross-Cultural Design (CCD 2017)
- 9th International Conference on Social Computing and Social Media (SCSM 2017)
- 11th International Conference on Augmented Cognition (AC 2017)
- 8th International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management (DHM 2017)
- 6th International Conference on Design, User Experience and Usability (DUXU 2017)
- 5th International Conference on Distributed, Ambient and Pervasive Interactions (DAPI 2017)
- 5th International Conference on Human Aspects of Information Security, Privacy and Trust (HAS 2017)
- 4th International Conference on HCI in Business, Government and Organizations (HCIBGO 2017)
- 4th International Conference on Learning and Collaboration Technologies (LCT 2017)
- Third International Conference on Human Aspects of IT for the Aged Population (ITAP 2017)

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1. LNCS 10271, Human–Computer Interaction: User Interface Design, Development and Multimodality (Part I), edited by Masaaki Kurosu
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HCI International 2018

The 20th International Conference on Human–Computer Interaction, HCI International 2018, will be held jointly with the affiliated conferences in Las Vegas, NV, USA, at Caesars Palace, July 15–20, 2018. It will cover a broad spectrum of themes related to human–computer interaction, including theoretical issues, methods, tools, processes, and case studies in HCI design, as well as novel interaction techniques, interfaces, and applications. The proceedings will be published by Springer. More information is available on the conference website: http://2018.hci.international/.

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