SeismoPen: Pulse Recognition via a Smart Pen

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ABSTRACT

We propose SeismoPen, an enhanced ballpoint pen, which is capable of calculating the patient's heart rate. This is enabled when being pressed the pen towards the patient's throat so it can sense and analyze the seismographic micro-eruption caused by the pulsing blood. We developed a suitable algorithm and tested three sensor setups in which we attached (1) a force-sensing resistor (FSR), (2) an accelerometer, and (3) a piezoelectric transducer to the pen's head. We also conducted a user study, which resulted in suggesting SeismoPen to be potentially more accepted by users, since it is less obtrusive than alternative measurement methods. In contrast to medical devices, this simple pen looks less perilous and potentially reduces the risk of triggering symptoms of a white coat hypertension.

ACM Classification Keywords

H.5.m. [Information interfaces and presentation];
J.3. [Life and Medical Sciences].

Keywords

Pulse Detection; Vital Signs; Pattern Recognition, Assistance, Medical Device; Smart Pen; Prototyping.

1. INTRODUCTION

Pulse is an important vital sign that provides information about a patient's physical and mental state. Therefore, pulse / heart rate (HR) detection is a very frequent task performed by physicians or nurses. There are various ways to sense the pulse, such as touching the throat and counting beats, using a stethoscope counting beats, applying an electrocardiogram (ECG), or using a blood pressure monitor. However, these techniques leave space for improvement. Analog measurement methods are usually very time consuming, inaccurate and require specific attention. Precise measurement devices are mostly bulky and not comfortable for the patient. Also, having the physician carry an additional device an entire day is less convenient than just utilizing a pen for a measurement (*see Figure 1*). Besides being lightweight, a pen is already carried within the physician's coat. Furthermore, as will be shown in this paper, a pen can provide precise pulse recognition, which is more accurate than a short measurement by a stethoscope. Additionally, it may help avoiding psychological side-effects such as white coat hypertension [11] and thus proves an attractive tool for pulse measurement.

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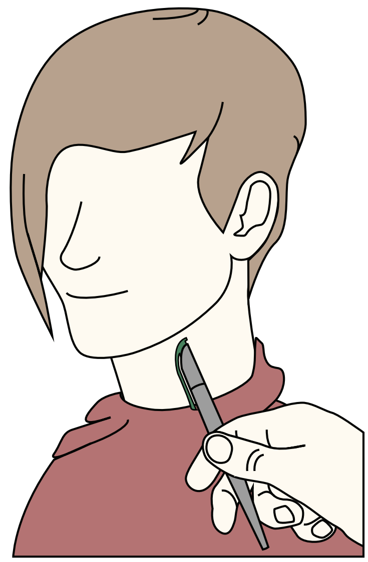

Figure 1. SeismoPen touches the throat artery of a patient and measures the seismographic micro-eruption caused by the pulsing blood.

2. RELATED WORK

Besides detecting the HR with conventional devices, such as an ECG or stethoscope, nowadays we can already find wearable devices that also provide vital parameters. In this section we will explain different approaches of sensing the user's HR.

A common way of pulse rate detection is to manually grab the wrist and to feel and count the pulse within a given time period. Many wearable devices in turn make use of optical sensors in order to detect the user's heart rate and saturation of peripheral oxygen. A common method to achieve this is pulse-oximetry, which is widely used. Such sensors are often implemented into finger-clips [3][8][9][10], or at the bottom site of a wrist worn device, such as a smartwatch [1]. In AMON, Anliker et al. [1] demonstrate a measurement of heart rate, blood pressure, ECG-activity, peripheral oxygen saturation, temperature and physical activity at the wrist position. However, in general, optical heart rate sensors, such as the ones used in smartwatches, are not precise enough to be used for medical purposes. Therefore, others utilize electrocardiography (ECG) to calculate the user's HR [6][7]. Hereby, the sensor measures a tiny electrical change on the skin that originates from the heart muscle contraction and depolarizes during each heartbeat. This method is demonstrated with various wearables, such as shirts with ECG electrodes. Other approaches, such as the one from Garverick et al. [4] use a continuous-wave Doppler ultrasound device for measuring the heart rate of a fetus. Another option is detecting the pulse from mechanical movements (e.g., through an accelerometer), such as demonstrated by Bieber et al. [2], who place a smartwatch directly onto the user's chest.

3. SEISMOPEN

In a medical context, we encounter several issues which also go beyond Human-Computer Interaction. On the one hand, around 20% patients are afraid to consult a physician, since medical devices predominantly look dangerous and are uncomfortable to the user (see white coat hypertension [11]). On the other hand, physicians or nurses usually do not find enough time to calm down the patients, since it would hinder them to work time-efficiently.

We want to overcome these problems by utilizing a completely new design. We figured out that designing a smart pen for a medical context implies several benefits:

- High social acceptance by the patients, since it is a known and harmless device
- Unobtrusiveness, since a pen is usually worn in the chest pocket of the physician's or nurse's coat
- Not bulky, since the pen is lightweight and comparably small
- Inexpensive compared to ECG devices

The SeismoPen thus constitutes a novel approach to provide unobtrusive assistance in vital data detection. Its' concept enables nurses and physicians to measure pulse in a manual and natural way with high accuracy.

4. IMPLEMENTATION

In order to proof our concept (*see Figure 2*), we tried three different sensor setups: (1) force-sensing resistor, (2) accelerometer, and (3) piezoelectric transducer.

Figure 2. Pressing the pen against the throat, enables a sensing of micro-eruptions caused by the pulsing blood. An Arduino Nano (ATMEL Mega 328PU) is used to push the data stream through a Serial connection, in order to visualize date on a computer in real time. A future product would also display the data at the pen and push the data on a server.

4.1 Force-Sensing Resistor (FSR)

A simple 0.3" 2.5kOhm FSR already provides a sufficient signal quality for a heart rate sensing – see Figure 3a.

The FSR is attached on the top of the ballpoint pen; a spring provides a defined pressure when held against the throat. The micro-eruption caused by the pulse can now already be sensed in a one-dimensional way – the change in resistance. However, this proof-of-concept already shows first disadvantages: the one-directional force measurement requires to (1) find the correct spot near the carotid artery, and (2) exert the right pressure. With current means, it is impossible to extract a sufficiently clean pulse signal when the pen is pressed too hard against the throat, or when the spot is chosen incorrectly.

4.2 Accelerometer

An AXDL 362 accelerometer, which is a low noise three-dimensional accelerometer quantizing +/- 2 g in a range of 12 bit – see Figure 3b.

The accelerometer concept provides the possibility of sensing the tissue movements in a three-dimensional space. The obvious advantage of using an accelerometer is that no force is needed to be applied in order to measure the pulse. Furthermore, the pulse rate can be detected in a wider area at the throat (near the main blood vessels).

In result, this proof-of-concept implementation showed a quite noisy signal, which unfortunately contains movements from the users hand while pressing the pen against the patient's throat. To solve this problem, a decoupling can be implemented in a possible subsequent version.

4.3 Piezoelectric Transducer

We utilized a Summer piezo D5-871 CPM 121 to translate low-amplitude body movements into a measurable electric current – see Figure 3c.

Compared to the accelerometer approach, the signal of the piezo sensor is mostly independent from external movement artifacts from the person holding the pen or the general surroundings. Therefore, a measurement is feasible when the user is located on or in a moving object (on a lounger or in an ambulance car). As a result, this proof-of-concept is favored, since it provides stable pulse peaks. Additionally attractive is the sensor's low energy consumption, which allows for a long period of use.

4.4 General Setup

Since the human pulse is a rather low-frequency signal, a sampling rate of 10Hz is sufficient for the purpose of detection. However, for the accelerometer approach we recorded at a higher frequency (50Hz). When using an accelerometer, counting peaks with a simple threshold analysis turned out to be difficult. That is why we composed the discrete signals into windows of 128 samples and applied a Fast Fourier analysis. A more detailed description of our heart rate extraction method can be found in the literature [5].

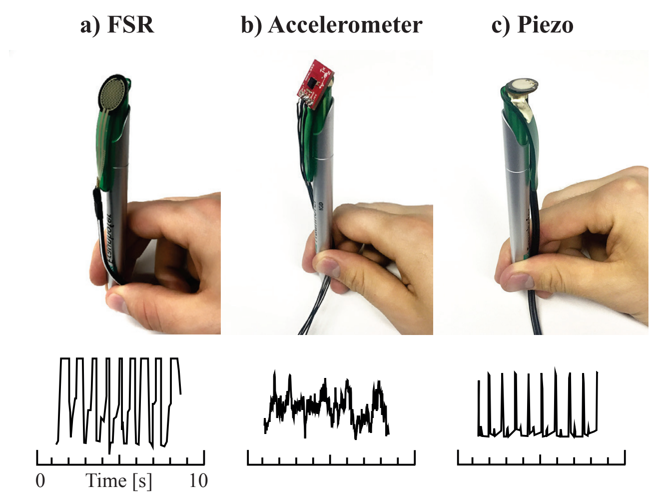

Figure 3. Prototypes (force-sensing resistor, accelerometer, piezoelectric transducer) with read out raw data. Even though the accelerometer signal requires much filtering, the pulse can be easily extracted.

5. USER STUDY

We have already proven the concept's technical feasibility. However, it is questionable whether the SeismoPen is also socially accepted by patients in a medical context and whether it might overcome or improve the problem of white coat hypertension [11]. Therefore, we designed a user study in which we were looking to find answers on two hypotheses (H):

H1: The SeismoPen will create less stress for the patients compared to other pulse measuring methods.

H2: The SeismoPen will yield a higher acceptance rate compared to other pulse measuring methods.

5.1 Study Design

We invited 10 participants (aged between 20-50 years, 9 males and 1 female) in an empty room. Every participant was instructed to strip the left arm and sit calmly on a chair, whereas the right arm had to lie on a table. In order to constantly monitor the user's state, we attached a Pulox pulse oximeter to the index finger of the right hand. In this setup, we ensured that the user's own vital parameter were not visible to the test subject (see Figure 4). As we recognized an increased pulse rate after changing from standing to sitting posture, we asked the subjects to watch an 8:22 min movie clip to calm their pulse and ensure a common test situation. Then, we first gave a short introduction and noted the subject's current pulse. Afterwards, we tested three pulse measuring methods which were performed in a random order for each test subject. During each condition, the current pulse rate was noted.

- **Kodea (professional) blood pressure monitor**
  On the subject's left arm, we applied an arm cuff. Following this, the measurement started while a loud air pressure pump started making noise. The left arm got squeezed by the arm cuff, which is part of the measuring process.
- **Self-test**
  The subject was instructed to lift his left arm towards the throat and to find a suitable spot, which allows for feeling the own pulse. During a 60-second time interval, the subject had to count all pulse beats. The result had to be communicated.
- **SeismoPen**
  The subject was quickly briefed about the function of the pen. Afterwards, the study leader was standing up towards the patient and pressing the SeismoPen against the subject's throat.

After performing all pulse measuring methods, the subjects were asked to rate the obtrusiveness on a 5-point Likert scale.

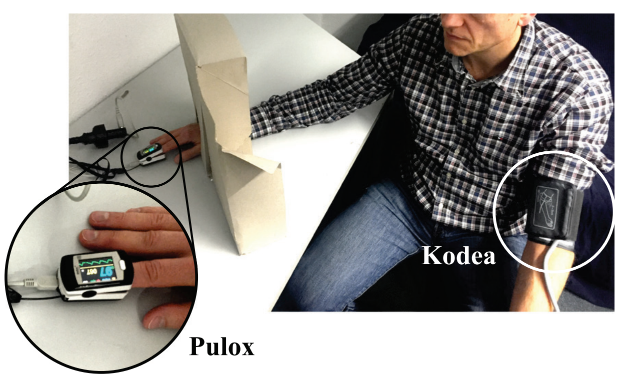

Figure 4. Setup: Pulox pulse oximeter constantly senses the subject's HR while the user is unable to see his own HR.

5.2 Results

During our study, we constantly noted the subject's pulse (introduction, Kodea, self-test, SeismoPen). Based on these measurements we calculated an average pulse for each person. We then calculated the percentage deviation for each condition in order to ensure cross user comparability. For the statistical analysis, we conducted a one-way ANOVA for independent samples ($F_{2,27}$ = 1.51) in order to see whether the data show significant differences. The results can be seen in Figure 5.

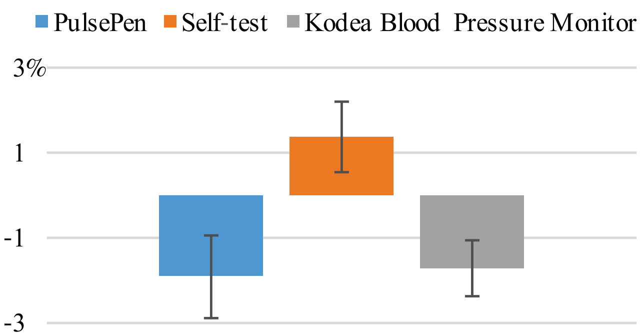

Figure 5. Deviation from the calculated average pulse rate. error bars indicate the standard error.

Even though we can see that the subjects were more stressed when doing the self-test (M = 1.678; SD = 5.185) and that using the SeismoPen (M = -1.905; SD = 6.085) yielded the lowest pulse we cannot perceive any statistical significant difference (p = 0.238) in both cases which was the same compared towards the Kodea blood pressure monitor (M = -1.721; SD = 4.121).

Although we have to reject **H1** due to a statistically non-significant result, we can already see a trend here. Note: The observable effects might have been statistically proven with a larger sample size.

To answer our second hypothesis (systems obtrusiveness), we let the participants rate all measurement methods on a 5-point Likert scale (1: highly obtrusive & uncomfortable – 5: highly unobtrusive & comfortable). The results can be seen in Figure 6.

A Friedmann test (k=3) confirmed a significant difference in the perception of obtrusiveness ($\chi^2(2)$=6.74, p=.0031).

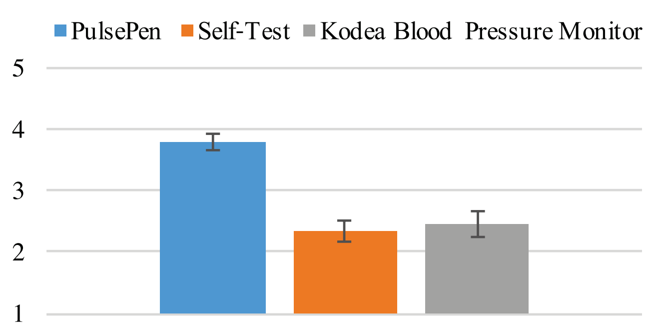

Figure 6. Subjective rating in terms of obtrusiveness. error bars indicate the standard error.

The recorded data suggest, that the SeismoPen (M = 3.8; SD = 0.788) is significantly more comfortable and unobtrusive for the user compared to both the self-test (M = 2.35; SD = 1.055) and the Kodea blood pressure monitor (M = 2.45; SD = 1.3) – thus we can accept **H2.**

6. ENVISIONED BENEFITS

Besides the basic heart rate detection we envision a variety of more sophisticated vital data detection scenarios for the SeismoPen. These scenarios are rather complex and therefore not measurable by hand. Nevertheless, parameters, such as pulse wave variability or pulse wave strength, contain health related information which can be crucial for diagnosing patients.

- **Pulse wave variability detection**
  Since the SeismoPen is able to detect the individual pulse waves, it enables for a detection of the variable distances between them. The pulse wave variability is strongly connected to the heart rate variability (as provided by ECG devices), which is an important indicator for physical and mental stress.
- **Pulse wave strength detection**
  SeismoPen can be used to determine the amplitude of single pulse waves. By this means, the level of pulse strength (e.g., weak, faint, strong, bounding) can be detected.
- **General anomaly detection**
  When detecting individual pulses and the individual pulse strength, anomalous signatures could also be detected. This includes phenomena, such as cardiac arrhythmia, extrasystoles, and tachycardia.

Besides the aforementioned scenarios, the SeismoPen can help inexperienced users to correctly measure the heart rate, since the pen can give feedback in case of improper handling. In this way, measurement inaccuracies can be avoided and crucial information related to the patient's current state of health can be gathered quickly. Moreover, a pen is a very basic object with a huge proliferation and therefore often ready to hand.

7. CONCLUSION

In this paper we proposed new design for a pulse measuring device, which is a simple ballpoint pen. Our design incorporates several benefits: it is small, lightweight, highly mobile, unobtrusive, and potentially more accepted by patients. We investigated three hardware setups in terms of sensor technology (FSR, accelerometer, piezoelectric transducer) and found all sensors to be able to sufficiently recognize the patient's pulse rate. A concluding user study also revealed the SeismoPen to be potentially more accepted than other pulse measuring methods.

8. FUTURE WORK

Future research will be devoted to the adoption of other application areas, such as the detection of respiration rate, blood pressure, and muscle vibrations through the pen. Even though the accelerometer signal looks noisy, we believe this sensor to have the most potential, since it is very sensitive and accumulates the aforementioned bio signals as well.

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