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Early-detection of pre-eclampsia: Concept and design of a portable prototype

https://doi.org/10.1515/cdbme-2024-2083

Abstract: Pre-eclampsia is one of the most common causes of maternal and perinatal death worldwide. It is a hypertensive pregnancy disease with reduced perfusion of numerous organs. The main symptoms of the disease include elevated blood pressure, proteinuria and the associated subcutaneous fluid retention in the fingers, hands and face of the pregnant woman. In this paper a concept of a portable prototype for early-detection of preeclampsia is presented. The assembled sensor systems enable portable monitoring of the main symptoms to detect changes at an early stage. The sensor system for determining blood pressure is based on photoplethysmography. The sensor system for detecting subcutaneous fluid retention uses the absorption bands of the fluid when illuminated with near-infrared light. For the validation experiments, finger models made of silicone with different fluid retention levels were produced. The results show a correlation between the measured transmitted light intensity and the fluid retention. The results represent a possibility for the portable measurement of important vital parameters in connection with preeclampsia.

Keywords: pre-eclampsia, early-detection, photoplethysmography, subcutaneous fluid retention

1 Introduction

Pre-eclampsia, a leading cause of maternal and perinatal mortality globally, is characterized by multisystem dysfunction and often manifests with hypertension, proteinuria and subcutaneous fluid retention [1-3]. Its diverse symptoms and late diagnosis contribute to adverse outcomes, including cardiovascular risks and preterm births [4,5]. This highlights the urgent need for simple early detection methods. Therefore, this paper aims to develop a portable prototype for early detection of pre-eclampsia. It focuses on monitoring characteristic parameters associated with this condition, particularly hypertension and fluid retention. This prototype aims to raise awareness among pregnant women, facilitate timely diagnosis, and empower self-monitoring, ultimately enhancing maternal health outcomes.

2 System Design

The presented prototype encompasses both partial functions of blood pressure measurement and measurement of subcutaneous fluid retention. The principle of photoplethysmography is utilized for blood pressure measurement, while absorption spectroscopy serves for the measurement of subcutaneous fluid retention.

2.1 Blood pressure measurement

In the presented research, the Pulse Express pulse ox & heart rate sensor (Protocentral Electronics, Bangalore, IN) was chosen for blood pressure measurement as it already includes an integrated algorithm for BP calculation [6]. The sensor captures the PPG signal using the integrated optical sensor MAX30102, which has a red and an IR light-emitting diode. The emitted light is detected by a photodiode (PD), converted by an analog-to-digital converter, are temporally filtered, and stored in a data register. The biometric sensor hub MAX32664D communicates via I2C with the optical sensor and further processes the digital output values. Through second I2C interface, the MAX32664D is connected to an Arduino Nano, which forwards the calculated BP values. To ensure that the measurement signal is not influenced by ambient light, the sensor is equipped with a daylight filter (see figure 1).

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In figure 1 c), it can be seen that the sensor box is constructed in such a way that the participant's finger is reliably placed directly on the sensor MAX30102 with its two diodes.

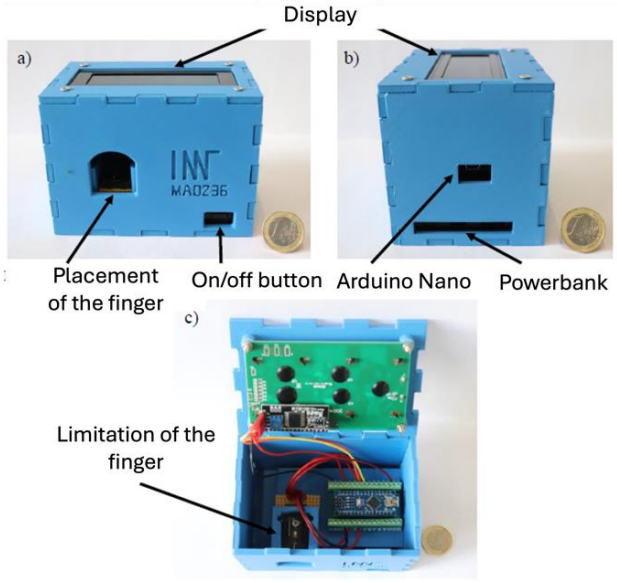

Figure 1: prototype blood pressure measurement

2.2 Detection of subcutaneous fluid retention

Due to the different optical properties of materials occurring in human tissue, tissue composition can be determined. Early detection of fluid accumulation in tissue is described in some studies using Near-Infrared Light (NIR). It is assumed that individuals with edema compared to those without edema exhibit increased absorption in the NIR range [7].

A wavelength of 970 nm is conducive to detecting water in deeper layers of the skin, including the dermis and subcutis, as water exhibits one of its five absorption bands in the NIR at 970 nm, rendering this wavelength suitable for penetration into said skin layers.

As exclusively the increase in fluid and not potential alteration in other tissues within the finger have been defined as relevant for the early detection of preeclampsia, the sensor system is augmented with an additional blue LED, intended to have a peak wavelength of approximately 478 nm (see figure 2).

Consequently, an IR-LED970D-03 with a peak wavelength of 970 nm and a radiant power of 30 mW (Roithner Lasertechnik GmbH, Vienna, AT) and a blue LED with a peak wavelength of 465 nm and a radiant power of 90 mW (Würth Elektronik Eisos GmbH & Co.KG, Waldenburg, DE) were used. The photodiodes utilized were the PD BPW34FAS-Z and PD BPW34 (OSRAM Opto Semiconductors GmbH, Regensburg, DE), possessing a spectral sensitivity of over 90% at the peak wavelength.

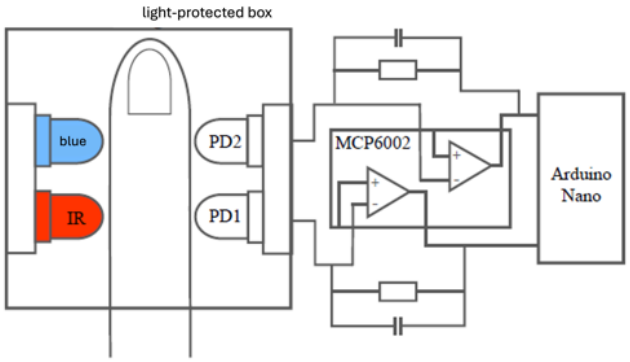

Figure 2: system of subcutaneous fluid measurement

3 Materials and Methods

3.1 Blood Pressure

After finishing the design of the prototype, a study was conducted with 21 participants, including twelve women and nine men aged 23 to 54 years; because this study focused exclusively on blood pressure measurement, male participants were also included.

Sixteen participants underwent measurements with the Blood pressure (BP) cuff on the left upper arm. Three of the participants were diagnosed with hypertension, two of whom take BP-lowering medication daily, and one has low BP.

Three measurements with the cuff are performed according to standardized procedures. The average values are noted as calibration values in the sensor code. Subsequently, 60 values are recorded within one minute with the sensor.

Furthermore, a long-term study was conducted over 12 days to monitor the BP trends in one participant. Measurements were taken once daily at 8 p.m., using the left index finger and a blood pressure cuff.

3.2 Subcutaneous fluid retention

Silicon finger models were made to evaluate the detection of subcutaneous fluid retention. The base material of the finger models is Ecoflex 00-50 silicone (KauPo Plankenhorn e.K., Spaichingen, DE). Each finger model consists of a silicone

cylinder into which liquid (0,9% NaCl) can be injected in the center. Eight different finger models are produced with diameters of 17 or 20 mm and liquid content of 0,2,3 or 5 mm (see figure 3).
The models are named according to their silicone or liquid content. For example, model 17-0 has a total diameter of 17 mm and a liquid content of 0 mm. Model 18-2 has a diameter of 20 mm and a liquid content of 2 mm. In total, ten voltage values were measured for each of the eight finger models while the IR LED illuminates the model, and ten voltage values were measured while the blue LED illuminates the model.

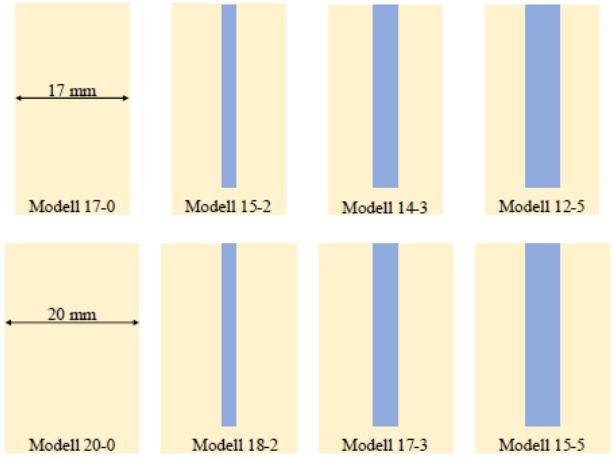

Figure 3: Silicon finger models

4 Results

4.1 Blood Pressure

The maximum absolute deviation between the systolic blood pressure measurement (SBP) of the blood pressure cuff and the PPG sensor is 11 mmHg, corresponding to a percentage deviation of 7.9 %. The minimum absolute deviation of the SBP is 0 mmHg. On average, the absolute deviation is 4.1 mmHg (3.3 %). Regarding the diastolic blood pressure measurement (DBP), a maximum absolute deviation of 5 mmHg (7.0 %) and a minimum absolute deviation of 0 mmHg are observed. The average absolute deviation of the DBP is 2.8 mmHg (3.6 %). The results also indicate that the standard deviations in BP measurement with the cuff are on average about 2 mmHg (SBP) and about 1 mmHg (DBP) higher than with the developed sensor system.
Also, 85.7 % of the subjects prefer the sensor system on the finger.

In the longitudinal study, the average absolute deviation of the SBP is 1.3 mmHg (1.12 %). The maximum absolute deviation is measured on day ten, reaching 3.3 mmHg (2.7 %). For DBP measurement, the average absolute deviation is 2.0 mmHg (2.7 %). The maximum absolute deviation also occurs on day ten, reaching 7.4 mmHg (9.4 %).

4.2 Subcutaneous fluid retention

The measured voltages of two finger models are compared to assess whether changes in silicone or liquid content can be predicted. Figure 4 displays the average percentage change in voltage during irradiation with IR light when the liquid content changes by 0, 1, 2, 3 or 5 mm.

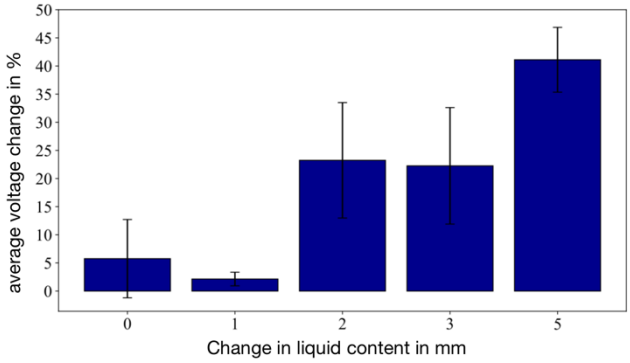

Figure 4: percentage change in voltage under IR-light

When comparing two finger models with equal silicone content but varying liquid content, no significant change in voltage is observed during measurement with the blue LED.
In the scenario where both silicone and liquid content increase from one finger model to another, the measured voltage values differ significantly during both, IR light and blue light measurements. For instance, comparing Model 17-0 and Model 18-2, there is a decrease in voltage by 32.07 % during IR light measurement and by 72.22 % during blue light measurement.
In cases where the silicone content decreases and the liquid content increases, a decrease in voltage is noted during IR light measurement in 17 out of 19 pairwise comparisons of the finger models.

5 Discussion

A participant and longitudinal study was conducted to evaluate the suitability of PPG technology for blood pressure measurement during pregnancy. The study included 21 participants, including both, men and women. The

developed sensor system showed comparable accuracies with an existing BP measuring device and was found to be more comfortable by the participants. The average deviations for SBP and DBP were low. The positioning of the finger did not significantly influence the measurement results. The measurement with the sensor system took slightly longer on average than with a conventional cuff, but participants preferred the sensor system due to its simplicity and the ability to measure multiple vital parameters simultaneously. The longitudinal study showed that the sensor system provided reliable results over a period of twelve days. Overall, PPG technology is a suitable solution for blood pressure monitoring during pregnancy, as it provides sufficient accuracy and is perceived as more comfortable than conventional methods.

The measured voltages exhibit a low standard deviation overall, implying resilience to ambient light influences. Out of the 28 comparisons between two finger models investigated, correct prediction of fluid infiltration change was achieved in 21 instances, corresponding to a precision of 75 %.

In the conducted tests with constant silicone content and varying liquid content, the change in liquid content could be accurately predicted with the measured voltages of the sensor system.

6 Summary and Outlook

A concept for a portable prototype for the early detection of pre-eclampsia has been developed. It includes two sensor systems: one for measuring blood pressure and one for detecting subcutaneous fluid retention in finger models. Validation of the blood pressure sensor system showed high agreement with the measurements of the blood pressure cuff. The fluid retention sensor system is based on absorption spectroscopy and demonstrates a correlation between measured voltages and fluid retention. Regarding to that, the next steps require an adjustment of the finger models to better meet the characteristics of human fingers. Following that, the transferability to human participants' fingers will be of interest.

This work lays an important foundation for early pre-eclampsia detection and can also be applied to other heart or kidney conditions. Future adjustments include integrating the two sensor systems, conducting further participant studies, and improving technology for more accurate diagnosis.

Author Statement

Research funding: The author state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration.

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