Sensor applications

# Wearable Ring-Based System for Measuring Hemodynamic Parameters

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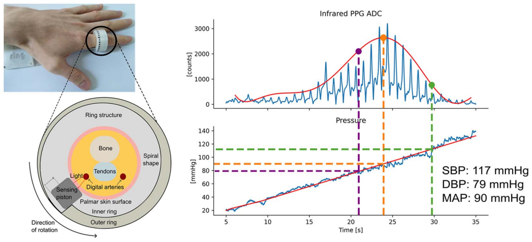
Abstract—Currently, there are no reliable and convenient wearable solutions for measuring blood pressure, which remains a key indicator of cardiovascular health. Many existing measuring systems are bulky, complex, and expensive, which limits their practicality for everyday use for wearable application. We introduce a compact, ring-shaped blood pressure measurement device as a proof-of-concept. It is based on a local oscillometric spot measurement obtained from the base of the index finger. The ring is made of two parts, where the outer sleeve induces pressure to the finger, and the inner guide bushing houses a ring sensor unit, which incorporates a commercial photoplethysmography module and a force-sensitive resistor. Manual rotation of the outer part of the ring applies pressure that occludes the digital artery, allowing estimation of blood pressure. For evaluation, we compared the results from our device with reference measurements from a brachial cuff blood pressure monitor. Ten volunteers underwent three to six measurements. The ring was able to capture moderate-quality oscillometric responses. The results (Bland–Altman: systolic mean difference $\mu = 1.1$ mmHg and standard deviation $\sigma = 9.5$ mmHg, diastolic $\mu = 0.1$ mmHg and $\sigma = 13.4$ mmHg) demonstrate the feasibility of the approach. There are still many sources of uncertainty, but these results highlight the potential of this new setup. As a proof-of-concept, the current setup lays the groundwork for future improvements. With further mechanical refinements and system simplifications, this wearable ring offers a promising pathway to accessible, comfortable, and portable blood pressure monitoring.



Index Terms—Sensor applications, biomedical monitoring, blood pressure (BP), photoplethysmography (PPG), pressure sensor, proof-of-concept.

## I. INTRODUCTION

Hypertension is a global health burden [1], making blood pressure (BP) a fundamental parameter for monitoring cardiovascular health [2]. Although BP can be measured using different approaches, continuous—or even frequent—simple, reliable, and noninvasive BP monitoring remains a challenge. Highly compact devices capable of reliable and user-friendly spot measurements could shift cardiovascular care from reactive treatment to proactive intervention, enabling the early detection of subtle hemodynamic changes prior to the disease onset. Many current wearable BP devices rely on surrogate markers or indirect estimations, such as pulse arrival time [3] and pulse transit time (PTT) [4]. While they might not achieve full clinical accuracy, they provide valuable insight into underlying health issues. There remains a need for both the development of promising new methods and the refinement of existing ones to improve accuracy and reliability.

To address the lack of continuous monitoring methods, we developed a compact, ring-shaped device that allows the user to take frequent spot BP measurements using oscillometric technique. The required electronics, pressure control, and sensing components were miniaturized into the form factor of a small ring. By integrating oscillometric measurement and photoplethysmography (PPG) signal acquisition in a wearable format, this device offers a promising solution for simplified, comfortable, and clinically significant on-demand BP monitoring.

The device operates by applying increasing pressure through a sensor unit embedded in a piston, which is pressed against a digital artery. The sensor unit consists of an optical reflectance-mode PPG sensor, which is attached on top of the piston, and a force-sensitive resistor (FSR) placed behind the optical sensor. The external pressure of the piston to a digital artery is created by converting rotational motion of the outer part of the ring into vertical movement of the piston, which in turn produces an oscillometric response that is commonly used in noninvasive BP monitors [5], [6]. In the oscillometric technique, blood flow is restricted by increasing the external pressure around an artery until the flow is completely occluded [7]. During this process, the pulsations (referred to as oscillations) increase to a maximum amplitude and then decline. The mean arterial pressure (MAP) aligns with the pressure at which the maximum oscillation amplitude occurs, from which the systolic and diastolic values can be estimated using algorithms [8]. Traditionally, the oscillometric response is recorded by measuring the pressure inside the cuff wrapped around the region of interest, and then extracting the oscillogram using standard signal processing methods.

We opted to use a piston-induced pressure on a small area in order to achieve more miniaturized size. Using a piston is effective for extracting oscillometric information by applying external pressure directly on a small artery, such as a digital artery [9]. These oscillometric signals can be captured with a PPG sensor, which is able to detect variations in blood volume [10], [11]. This demonstrates that BP can be measured using a combination of pressure sensing and PPG, especially when using longer wavelengths in the visible spectrum to infrared (IR) wavelengths [12]. These longer wavelengths are necessary to penetrate the skin tissue deep enough to reach the digital arteries, because the

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wavelength of the light determines the penetration depth of the light into the skin [13].

## II. RELATED WORK

In recent years, progress has been made in the miniaturization of BP monitoring devices. A miniature cuffless tonometric finger probe system has been developed, employing the oscillometric method to measure BP [14]. Similarly, a miniaturized wireless BP sensor interface utilizing capacitive coupling has been proposed [15]. Other noninvasive methods include PTT estimation using electrical bioimpedance and continuous-wave radar [16], as well as hybrid approaches that integrate electrocardiogram and optical fiber PPG sensors [17], [18].

Wearable solutions have also gained traction, including smartphone-based systems that apply the oscillometric finger-pressing method [19], impedance plethysmography rings [20], and flexible piezoelectric sensors placed on the finger to capture pulse waveforms [21]. Several commercial devices, such as the Omron HEM-6411T-MAE with a form factor similar to a clock, have also emerged, making these innovations accessible for everyday use.

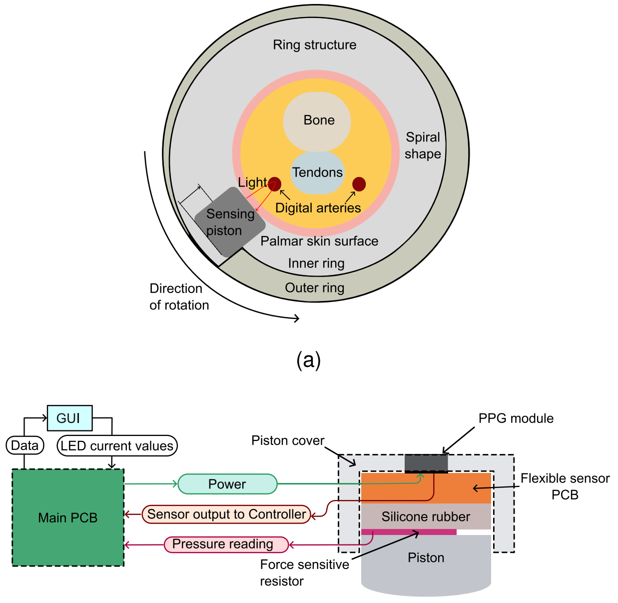
## III. SYSTEM DESCRIPTION

The proposed wearable ring consists of separate inner and outer parts, where the inner part is in contact with the finger and also contains the hole for the piston. The outer part connects to the inner part with a ball bearing to minimize friction between the parts during rotational movement. The outer part has a continuous spiral shape where the relative thickness of the wall changes depending on the radial location. The thickness of the outer part increases during the rotational movement, pushing the piston against the skin, transforming the rotational movement performed by the user into vertical movement of the piston. The hole in the inner part helps the sensor unit maintain its radial direction during vertical motion. The outer part can rotate approximately 270° from the initial position, with the external pressure increasing approximately to 150 mmHg when fully rotated to the end. The ring is placed to the base of the finger. The design and working principle are illustrated in Fig. 1. While the user rotates the outer part, the user is instructed to increase the pressure linearly, guided by the graphical user interface (GUI).

### A. Sensor and Electronics

The system consists of two printed circuit boards (PCB): a main PCB and a sensor unit PCB. Both were custom-designed in-house, with fabrication outsourced. The sensor unit comprises a piston mechanism, an FSR (GD-05, UNEO Inc., Taiwan) and a commercial publicly available PPG module (MAX30101, Maxim Integrated, USA) with an estimated power consumption of 1.8 mW in standard mode. The PPG module itself has an integrated IR LED with peak wavelength of 880 nm and receiving photodiode. The FSR has a high resistance while being unloaded. When external pressure is applied to a finger with the pressure generation mechanism, the FSR located under the PPG sensor experiences a measurable change in resistance, allowing monitoring of pressure dynamics. The PPG module communicates with the main board through the interintegrated circuit interface. The module includes all electronic components required to detect changes in light absorption caused by pulsatile blood flow.

The sensor PCB is flexible and is connected to the main PCB. The main PCB contains the system-on-chip (SoC) ESP32-S3 (Espressif Systems, China), which has a built-in analog-to-digital converter. In addition, the main PCB contains voltage regulators (MIC5253-1.8YC5-TR, Microchip Technology Inc, USA and AP2112K-3.3TRG1, Diodes Inc., USA), a voltage booster (CAT3200TDI-GT3, Onsemi, USA), an operational amplifier (MCP6061T-E/OT, Microchip Technology Inc, USA), and level-shifting MOSFETs (BSS138, Onsemi, USA). These are required to fulfill the different voltage requirements of the SoC and the PPG module. The main PCB controls the sensor unit, timestamps the data, and communicates with a connected device through a GUI.



(a)

(b)

Fig. 1. Illustrative figure of how the sensing piston probes the digital artery with light. (a) Structural composition of the finger and cross-sectional view of the device and finger. During a measurement, the inner part of the ring stays in place while the outer part rotates around it. Due to the spiral shape and the (b) piston with the sensors rises against the skin when the outer part rotates. The ring is positioned so that the piston is perpendicular to a digital artery. The piston is illustrated with a simple system flow diagram.

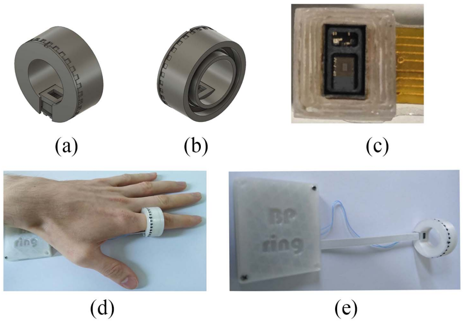
The mechanical designs were created using the Autodesk Fusion 360 computer-aided design software and the parts were manufactured using the Creality CR-20 Pro fused filament fabrication 3-D printer.

### B. Software

*1) PC Software:* The GUI was developed in Python and runs on a laptop connected to the main board of the ring via USB. It provides visual guidance for the user by displaying the target rotational motion profile with live feedback. Sensor data are streamed via serial communication and visualized in the GUI, which include PPG waveform, FSR readings, current pressure, the target slope of pressure increase, and measured pressure in relation to ideal pressure. All incoming data stored in comma-separated value file for postprocessing and analysis.

*2) Firmware:* We chose ESP32-S3 as the SoC due to its simplicity and customizability. The SoC was programmed in the C programming language using the Espressif Internet-of-Things development framework. The firmware takes commands from the GUI, which allows the user to change the device settings and control the measurement process. The sampling rate of the system was 100 Hz.

*3) Algorithm:* The following pipeline was used to extract oscillograms and MAP values from the raw data. The raw PPG signal was inverted to ensure that the systolic peaks pointed upward. The signal



(a) (b) (c)
(d) (e)

Fig. 2. Visual representation of the device. (a) 3-D model of the ring pictured from the front. (b) Same model pictured from the back, showing the ball bearings connecting the inner and outer parts of the ring to minimize friction. (c) Close-up view of the PPG module. (d) Photo of the device attached to the index finger of the left hand. (e) Photo of the device.

was filtered using a fourth-order zero-phase Butterworth bandpass filter with cutoff frequencies of 0.5 and 8 Hz to extract the pulsatile ac component. By performing a Hilbert transformation and taking its absolute value, we can extract the amplitude envelope. The peaks of this envelope were identified using a modified automatic multiscale peak detection [22]. A tenth degree polynomial fit was computed to these peaks, and the maximum value of the polynomial fit was found. The corresponding pressure value was then obtained on the FSR readings, which was calibrated and converted into millimeters of mercury. The analysis was done using Python programming language.

### C. Measurement Protocol

The ring orientation is determined prior to measurements by rotating the entire ring approximately 200° on the palmar side of the finger while recording PPG signals. Because the PPG signal varies with the amount of probed blood volume, the photodiode output decreases under the digital arteries. This ensures that the sensor unit is placed directly under the digital artery for optimal signal quality. The correct placement and the structure of a finger are presented in Figs. 1(a) and 2.

During the oscillometric measurement, the device is connected to the GUI, which guides the user to tilt the ring to the optimal angle. The pressure is increased above systolic pressure until no more meaningful signal is detected in the ac component. At this point, the outer part of the ring is rotated back to its initial position to relieve the pressure.

## IV. HUMAN STUDY

Healthy volunteer measurements were performed for ten subjects without diagnosed cardiovascular disease (mean age 26 ± 3 years, range [23, 32]), of whom five were women and all Caucasian. Each subject underwent three to six measurements to guarantee as many good measurements as possible. Beforehand, the subjects were familiarized with the device and measurement protocol and chose a ring based on their index finger size. All measurements were performed in a sitting position and from the base of the index finger. Of the 37 measurements, 16 were excluded due to poor measurement quality, mainly caused by incorrect rotational motion or ring placement on the finger, resulting in the exclusion of three subjects. Reference measurements were taken from the brachial artery (Omron, M2 HEM-7143-E, Omron Healthcare Co., Japan). After 5–15 min of seated rest, ensuring stable BP, BP measurements were taken from the upper arm. The subjects were seated so that the arm would be at the same level as the heart to prevent the position-dependent hydrostatic pressure effect. The performance of the ring-shaped system against the golden standard reference device is depicted in Figs. 3 and 4. The study was approved by the Ethics Committee of the University of Turku and was conducted according to the Declaration of Helsinki guidelines. Written informed consent was obtained from all study subjects.

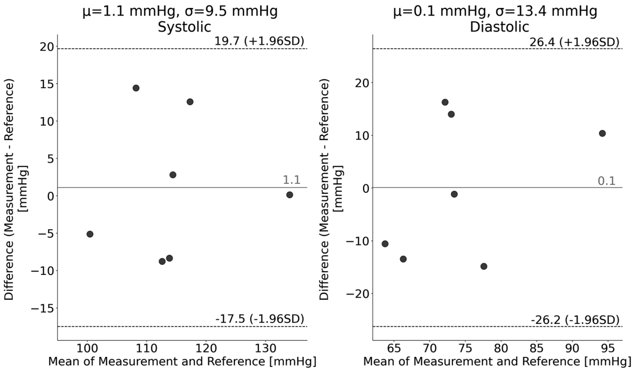


Fig. 3. Bland–Altman plots for showing error of SBP and DBP between the measured data and the brachial reference device data. Mean error (μ) and standard deviation ($\sigma$) are computed for each plot.

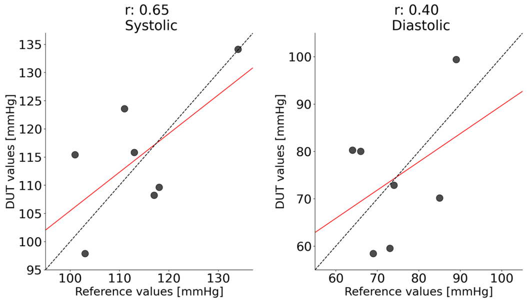


Fig. 4. Correlation plots for SBP and DBP between the measured data and the brachial reference device data. Correlation coefficient $r$ is depicted for both plots.

## V. EXPERIMENTAL RESULTS

In this pilot study, the device was able to extract moderate-quality oscillograms, as seen in Fig. 5. It is worth noting that continuous rotation as linearly as possible is crucial for this type of setup, which is also the reason why some of the measurements were excluded due to low quality. The errors caused by slightly uneven rotation are visible in the collected signals. These are the result of readjusting the hand or the fingers responsible for rotating the outer part of the ring.

We used a Bland–Altman analysis and correlation plots to assess the agreement between the measured values and the brachial reference to evaluate the reliability of the results. The selected ratios [0.82 for Diastolic Blood Pressure (DBP) and 0.24 for Systolic Blood Pressure (SBP)] were chosen based on an empirical optimization process, in which these ratios produced the lowest error compared to reference measurements. The mean error (μ) and standard deviation ($\sigma$) for SBP and DBP were $(1.1 \pm 9.5)$ mmHg and $(0.1 \pm 13.4)$ mmHg, respectively. The correlation coefficients $r$ with SBP = 0.65 and DBP = 0.40 suggest moderate correlations with the reference values.

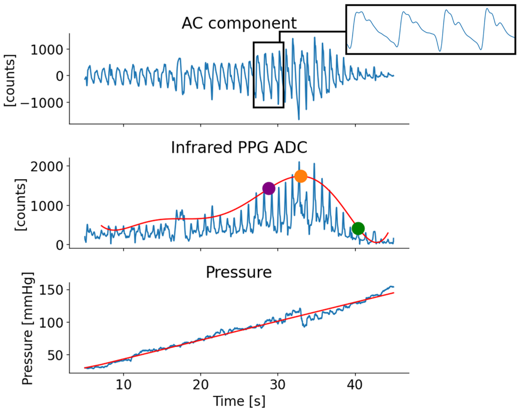


Fig. 5. AC component of the raw signal, oscillogram with a tenth degree polynomial fitted to the detected peaks and the corresponding external pressure (calibrated to mmHg), resulting from piston elevation due to rotation of the outer ring. These are presented as a function of time. It is evident how slight inconsistencies in the rotational motion, reflected as a drop in the pressure signal, affect the detected pulse amplitudes, potentially contributing to errors in SBP and DBP estimations.

## VI. CONCLUSION

The purpose of this pilot study was to demonstrate the feasibility of performing oscillometric measurements using a simple wearable ring setup. The presented method was able to accomplish this with a slight caveat: the user needs to be familiar with the device to correctly position and smoothly operate the ring. Subject-specific factors, such as the hand temperature and the thickness of the skin, can affect the quality of the extracted oscillogram. Temperature can be measured using a temperature sensor, which is already integrated to the commercial MAX30101 sensor. This was not used, because the aim was to prove the concept and not make clinical evaluations. It can also be easily noted when the temperature of the finger falls under optimal levels from the decrease in signal quality. Finally, the user must be able to monitor the pressure increase in real time and maintain a consistent rotational motion for accurate signal acquisition.

Systolic pressure readings appear more accurate than diastolic pressure readings, contrary to typical expectations. We attribute this to the diastolic side being more vulnerable to rotational motion errors, due to lower contact pressure. Although the amplitudes on the systolic side drop sharply near occlusion, limiting the time window for motion-related disturbances, the diastolic side approaches the MAP more gradually, increasing its exposure to signal distortion. Future research directions include system refinements and simplifications, making it easier to use.

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