eBP: A Wearable System For Frequent and Comfortable Blood Pressure Monitoring From User’s Ear

Nam Bui+, Nhat Pham+, Jessica Barnitz+, Zhanan Zou+, Phuc Nguyen+, Hoang Truong+, Taeho Kim+, Nicholas Farrow+, Anh Nguyen+, Jianliang Xiao+, Robin Deterding+, Thang Dinh* and Tam Vu+.

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Blood Pressure is the key vital sign for many diagnosis.
Common BP monitoring devices.

Arm-cuff BP monitoring

Wrist-cuff BP monitoring
Hypertension – Ambulatory Blood Pressure Monitoring (24 hours)
eBP: In-ear Blood Pressure Monitoring System

- Convenient
- Unobtrusive.
- Frequent & long-term usage.
Analysis of arterial system around the ear

Superficial Temporal Artery

Posterior Auricular Artery
Fundamentals of Arm/Wrist Cuff Mechanism
Introduce In-ear Blood Pressure Monitoring
Photoplethysmogram (PPG) Pulse Sensing

Artery

Pulse Sensor
Challenge: Arteries inside the ear cannot be completely blocked by the balloon.
Oscillometric BP measurement

Mean Arterial Pressure ($A_M$)
In-ear blood pressure measurement model
Relational equation between the MAP, systolic, diastolic BP

- The Mean Arterial Pressure (MAP): is the average value of BP in one cycle.

\[ P_{MAP} = \frac{1}{\tau} \int_0^\tau P(t) dt \]

- Assuming:
  - Pulse duration \([0, \tau]\)
  - \(\beta = \Delta t_s/\Delta t_c\) is the systolic fraction.
  - The systole is in the interval \((0, \tau\beta)\) and diastole is from \((\tau\beta, \tau)\).

\[ P_{MAP} = \frac{1}{\tau} \int_0^{\tau\beta} P(t) dt + \frac{1}{\tau} \int_{\tau\beta}^\tau P(t) dt = \beta \left[ \frac{1}{\beta \tau} \int_0^{\tau\beta} P(t) dt \right] + (1-\beta) \left[ \frac{1}{(1-\beta)\tau} \int_{\tau\beta}^\tau P(t) dt \right] \]

- \(P_M = \beta P_S + (1 - \beta) P_D\)

- \(\beta = \Delta t_s/\Delta t_c\)
Challenge: In-ear balloon design.

- Medical Safe.
- Bio-compatible.
- User’s comfort.
- Be able to attach Pulse sensor.
- Fit inside the ear.
- Be Inflatable inside the ear.
Making the balloon

- Inflatable port
- Pulse sensor
- Liquid silicone gel
- Flexible circuit
- Harden size
- Soft silicone
- Photodiode & LED array
- 1cm
- 15
Prototype

Solenoid valve
Connector

Pressure sensor

CM-Choke and ESD protection

3V mini pump
Connector

AFE4404

Solenoid
valve

10-pin-to-10-pin cable

In-ear pulse sensor

Bluetooth module

MSP43OF5529

Catheter balloon

MSP
### Demographic data of study population

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>18 - 35 years old</td>
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<tr>
<td><strong>Blood Pressure</strong></td>
<td>Systolic: 93-146, Diastolic: 53-113</td>
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<tr>
<td><strong>Gender Ratio</strong></td>
<td>Male: 24, Female: 11</td>
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**Ground truth device:** KonQuest KBP-2704A

**Calibration:** Polynomial regression model on the data of 5 subjects.
Result

Association for the Advancement of Medical Instrumentation

Systolic BP

Diastolic BP

\[ \mu + \sigma = 9.0 \]
\[ \mu = 1.8 \]
\[ \mu - \sigma = -5.4 \]
Integrated to **earphone or a hearing aid** for frequently measuring BP

Improve the **algorithm of existing cuff** devices.
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