Abstract
Our project has two main objectives. First, we attempt to detect blood pressure changes continuously and non-invasively using EverOn (a mechanical sensor developed by EarlySense) and Pulse Oximeter. Following, we examine the possibility of contact-free detection of blood pressure, using two EverOn sensors.

We apply the concept of “Pulse Transit Time” (PTT) - the time it takes a pressure pulse to travel between two arterial sites. This indicator has been previously shown to be highly correlated with BP changes of healthy patients. Nevertheless, measured with ECG, pathologies and drugs can cause imprecision in the PTT, due to their effect on the Pre-Ejection Period. Therefore, we wish to calculate PTT using two mechanical sensors. The blood pressure of five subjects was deliberately increased by pressing a handgrip. An increase of 16.7mmHg in the Mean Arterial Pressure was accompanied by a decrease of 10.8ms in the PTT measured with EverOn and PPG. We observed good correlation between PTT and MAP (EverOn) and PulseOximeter or photoplethysmography (PPG).

Objectives
- Detect blood pressure (BP) changes continuously, non-invasively and with minimal contact, using EarlySense’s mechanical sensor (EverOn) and Pulse Oximeter or photoplethysmography (PPG).
- Examine the feasibility of a contact-free detection of blood pressure changes, using two EverOn sensors.

Methods
1) Data was collected from five subjects. The experiment’s protocol included: 5 minutes - rest (baseline), 5 minutes – deliberate BP increase by pressing a handgrip and 5 minutes – recovery. The gathered data included recordings of ECG, PPG, BP and two EverOn sensors (One placed under the chest and the other under the abdomen). All the signals were digitally filtered to remove noises.
2) Validation of PTT-BP correlation using ECG and PPG:
   • Determining the reference points on the ECG and the PPG signals.
   • Calculating the PTT value for each pulse.
   • Examining the correlation between PTT and BP.
3) Examination of PTT-BP correlation using EverOn and PPG following the same steps.
4) Checking the feasibility of using two EverOn sensors to calculate the PTT, using the same steps.

Results
The handgrip pressing caused a significant BP increase (p<0.001), and a significant PTT decrease (p<0.001).

Methods

<table>
<thead>
<tr>
<th>PTT ECG</th>
<th>PTT EverOn</th>
<th>MAP</th>
<th>SBP</th>
<th>DBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ms]</td>
<td>[ms]</td>
<td>[mmHg]</td>
<td>[mmHg]</td>
<td>[mmHg]</td>
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<tr>
<td>Baseline (rest)</td>
<td>300±119.7</td>
<td>80.8±46.6</td>
<td>122±84.6</td>
<td>63±36.1</td>
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<td>Maximal</td>
<td>280±118.3</td>
<td>97±37.7</td>
<td>140±31.7</td>
<td>73±84.3</td>
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<td>Effort</td>
<td>Δ = -20±3.2</td>
<td>Δ = -10.8±1.3</td>
<td>Δ = 16.7</td>
<td>Δ = 17.7</td>
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<tr>
<td>Recovery</td>
<td>298±16.3</td>
<td>80.4±5.2</td>
<td>124±10.7</td>
<td>63±3.8</td>
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<tr>
<td>Δ = 24±5.5</td>
<td>Δ = -0.3±3.9</td>
<td>Δ = -0.5</td>
<td>Δ = 1±2</td>
<td>Δ = -7.3</td>
</tr>
</tbody>
</table>

Non-Invasive Detection of Blood Pressure Changes Using EverOn and Pulse Oximeter
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Introduction
EarlySense LTD is developing a unique technology in order to supervise a patient’s physical conditions continuously (in particular, heart rates and movement activity), and predict deterioration in his clinical state in advance. The monitoring is achieved by a mechanical sensor (EverOn) which lies under the mattress, and advanced DSP algorithms.

Pulse Transit Time (PTT) is the time it takes a pressure pulse to travel between two arterial sites. Documented evidences indicate that PTT has high correlations when it is utilized as a surrogate monitor of abrupt BP changes. When the BP increases, pulse velocity increases and therefore the PTT value decreases.

Usually, the interval between the peak of the R-wave on the ECG and the onset of the corresponding pulse in the finger pad measured by PPG is defined as the PTT.

However, there is a considerable delay between the electrical cardiac activity (R-peak) and the mechanical ventricular ejection. This delay is referred to as the Pre-Ejection Period (PEP). The PEP is affected by pathologies, drugs and other factors, and therefore can cause imprecision in the PTT measurement, and in the PTT-BP correlation.

Use of two mechanical sensors (EverOn and PPG or two EverOn sensors) to measure the PTT, can produce a more accurate, non-invasive and continuous BP changes monitoring.

Discussion and Conclusion
• Difference in observed PTT using electronic-mechanic method and mechanic-mechanic method occurs due to the PEP. A direct measurement of PEP was performed using an electrocardiogram (ECG) and a mechanical one (EverOn sensor under the chest). The results are depicted below.

As shown in the graph, PEP remains constant (and in the normal range of 90-100 ms) during rest period, reduces during the effort period, and returns to its previous magnitude over the recovery.

• We believe that using PPG and EverOn sensors to measure PTT may serve as a reliable, non-invasive and continuous way to detect changes in blood pressure.

• Feasibility of using only EverOn sensors is supported by the data.

• We recommend that further research and more experiments be conducted to strengthen these results.

The gathered data included recordings of ECG, PPG, BP and two EverOn sensors (One placed under the chest and the other under the abdomen). All the signals were digitally filtered to remove noises.

• Checking the feasibility of using two EverOn sensors to calculate the PTT, using the same steps.

When two EverOn sensors were used (without PPG), a PTT decrease of about 9ms was observed.

BP and PTT series demonstrated strong correlation when the ECG and PPG sensors were used (MAP: p=0.08, SBP: p=0.085, DBP: p=0.82). When the EverOn and PPG sensors were used, PTT also showed good correlation with the BP (MAP: p=0.62, SBP: p=0.6, DBP: p=0.64).