BPASS: Device for Non-Invasive Blood Pressure and Arterial Stiffness Measurement

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Problem Statement

Cardiovascular disease is one of the top killers in today's society. Blood pressure and arterial stiffness are indicators of cardiovascular health. Currently, blood pressure is measured via sphygmomanometry and arterial stiffness via arterial tonometry. Although effective, the speed and accuracy of these methods can be improved. The goal is to design a system, comprised of a piezoelectric pressure sensor, an actuator, and a stabilizing structure, that can quantitatively measure blood pressure and arterial stiffness on a single artery.

Background

Blood pressure:

- Force of blood pushing against walls of the arteries[1]
- Systolic pressure: ventricles of the heart contract
- Diastolic pressure: relaxation of the heart between contractions
- Pulse pressure = systolic pressure - diastolic pressure[2]
- Average blood pressure for healthy adult: 120/80 mm Hg

Figure 1: Blood pressure cuff

Arterial stiffness:

- Elasticity of artery walls[3]
- Stiffen with age, atherosclerosis, and fraying of elastic fibers in artery walls[4]

Current measurement methods:

- Blood pressure via sphygmomanometry (blood pressure cuff) using auscultatory or oscillometric method
- Arterial stiffness via arterial tonometry

Motivation:

- Blood pressure cannot be measured on individual arteries
- Stiffness measurements slow: tonometry takes 10-15 min

Design Criteria

- Effectively and continually measure blood pressure using a pressure sensor on a single artery
- Measure arterial stiffness by applying an impulse force on the artery using an actuator
- Measurements should be taken non-invasively
- Should increase speed of measurement from current methods
- System should incorporate pressure sensor, actuator, and a stabilizing structure
- System must be comfortable for subject
- System should be easy to operate

Final Design

Piezoelectric pressure sensor:

- Sensor comprised of a crystalline material that accumulates charge and generates a potential when deformed[5]
- Placed within an aluminum block in order to effectively compress the artery while minimizing discomfort
- Sensor and aluminum block system incorporated onto an inflatable cuff (Figure 2)

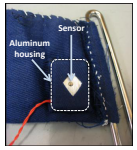


Figure 2: Sensor, Aluminum block, and cuff

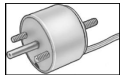


Figure 3: The push/pull solenoid used to actuate

Actuator:

- A combination linear push-pull solenoid (Figure 3)
  - Powered by 24V DC
  - Provide up to 30 oz. pushing force at a 3.175 mm stroke

Amplifying circuit:

- Sensor output is processed by a compound circuit (Figure 4 & 5)
  - Amplified 10-fold using LT1920 op-amp with +2.5 volts as reference
  - Low-pass filtered to screen out noise frequency higher than 40Hz
- Signal is displayed on a computer using Java

Figure 4: The complete circuit, wire wrapped to a microcontroller

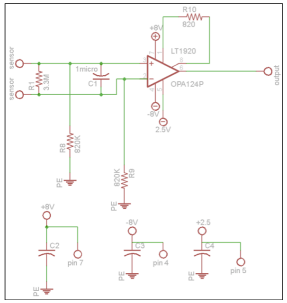


Figure 5: The complete circuit schematic

Stabilizing structure:

- Constructed to immobilize the patient's arm during testing
- Incorporates all components (Figure 6)

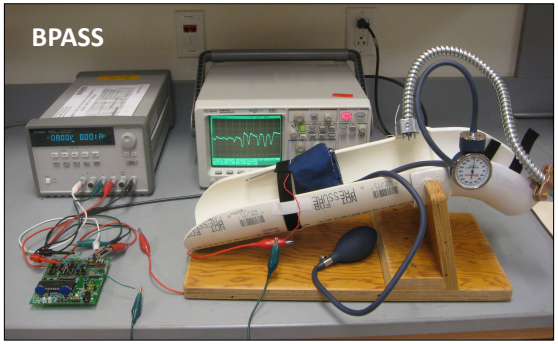
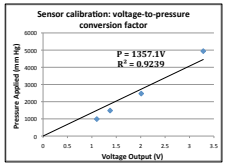


Figure 6: The complete testing setup – the stabilizing structure, the solenoid, the sensor and cuff, the amplifying circuit, the oscilloscope, and the power supply

Testing & Results

Sensor calibration:

- Masses ranging from 2-10 grams were set on the sensor
- Linear relationship obtained for converting voltage output to pressure



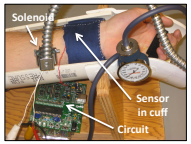


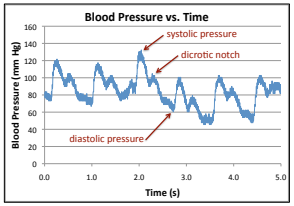
Figure 7: The cuff on the wrist and the arm on the stabilizing structure.

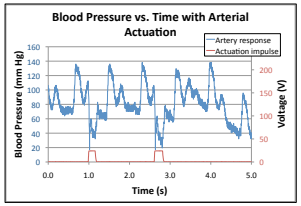
Blood pressure vs. time:

- Average pulse rate: 49.4 beats per minute

Arterial actuation:

- Average length of human-controlled actuation pulse: 162 milliseconds
- Average delay between actuation and response: 4.1 milliseconds
- Average artery response duration: 204.7 milliseconds

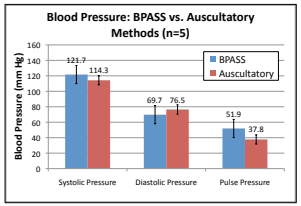




Method comparison:

- Average deviations of BPASS method from the auscultatory method
  - Systolic: 10.64 mm Hg, diastolic: 8.658 mm Hg
  - Pulse pressure: 14.71 mm Hg

Test Subject	BPASS Blood Pressure (mm Hg)	Cuff Blood Pressure (mm Hg)
1	120.6/81.8	112/74
2	113.0/61.0	116/82
3	140.1/75.1	125/80
4	113.0/61.0	104/70
5	137.5/80.6	120/80
Average	121.7/69.7	114/77



Future Work

- Appropriate pressure sensor with complete data-sheet
- Improved circuit to produce more precise and amplified signals
- Ultrasound device to locate the artery and determine artery compression
- Program for automatic actuation
- Program to continually measure blood pressure
- Approval from Institutional Review Board to test on human subjects

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