 Pediatric In-Shoe Physical Activity Dynamometer

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Developing strong bones early in life reduces the risk of osteoporosis in the future. [1]

According to the Mechanostat model, bone size and mass are impacted by the forces developed by muscles on bone during growth. [2-5]

A device to measure forces on bones, specifically in the legs, would be useful for research.

Device may also be used for research on:
- Obesity
- Childhood developmental disorders
Force Measurement Methods

- Observation and Reporting of Activity
- Accelerometer
- Force Plate
- Physical Activity Dynamometer (PAD)
  - Wired
  - Self-Contained (the Foot-PAD project)
Foot-PAD: Previous Work

- 2004 – Foot-PAD project initiated

- 2005-2008 – Piezoelectric (PVDF) sensors tested in shoe, circuit board initial design laid out

- 2009 – Piezoelectret sensors used

- 2010 – Piezoresistive sensors first used, new software developed
Project Goals

- Eliminate obtrusiveness
  - Reduce size of circuit board to less than 2 square inches
  - Use surface-mounted components
  - Conceal the entire device within a shoe

- Reduce inaccuracy
  - Avoid sensors that depend heavily on temperature
  - Measure forces in the direction of application
  - Perform calibrations to demonstrate data fit
FlexiForce Sensor

- Chosen for use in device
  - Low susceptibility to gradual temperature changes [6]
  - Designed to measure vertically applied forces
- Change in resistance quantized by voltage divider

\[ V_{out} = V_{in} \left( \frac{R}{R + R_{FF}} \right) \]
Circuit Board Construction
Modifications decreased the total chip area by 40% down to 1.88 square inches.

The chip height was decreased by over 100% by removal of the battery.
Testing without Shoe

- Initial testing was conducted to determine the device functionality before installation in the shoe.
- For calibration, the known forces were applied with a device based on beam theory.
Calibration Curve

Calibration External to Shoe:
Force vs. ADC Output Signal

\[ F_{FF} = 0.011(S_{ADC}) \]
\[ R^2 = 0.984 \]
Installation into Shoe

- The circuit board, sensor, power supply, switch, and a 6-pin extension cord were all inserted into a shoe for testing.
- The platform shoe used was a Vans skateboarding-style shoe.
  - Removable insole
  - Padded walls and tongue
- Only the switch and 6-pin connection were visible.
In-Shoe Calibration

Calibration Internal to Shoe:
Force vs. ADC Output Signal

\[ F_{FF} = 6.508 (S_{ADC}) \]
\[ R^2 = 0.967 \]
In-Shoe Test Data

Forces while Walking and Jogging vs. Time

- Walking
- Jogging

Force (lbs) vs. Time (sec)
Conclusions

- The strong correlation between the actual forces and ADC output during calibration suggests that there will be little inaccuracy in any subsequent measurements.

- Concealing the sensor completely within a shoe has been successfully addressed.

The Foot PAD device, in progress since 2004, has finally overcome its main problems and been produced in a usable form.
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