Garmin International: Energy Harvesting in Fitness Electronics

MAY14-17

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Iowa State University

Industrial Review Panel, Spring 2014

Outline

Outline

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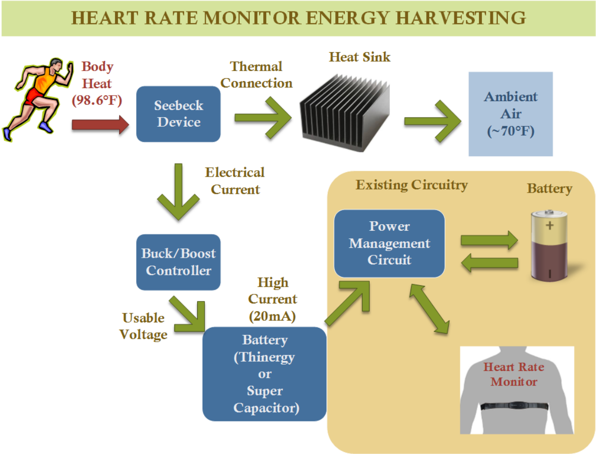
Problem Statement

- Garmin International produces several wearable fitness monitoring devices
- The goal was to find a way to maximize the battery life of at least one of these devices through the use of energy harvesting
- Another goal was to create a research document reporting on the group's findings for Garmin to use in their future products

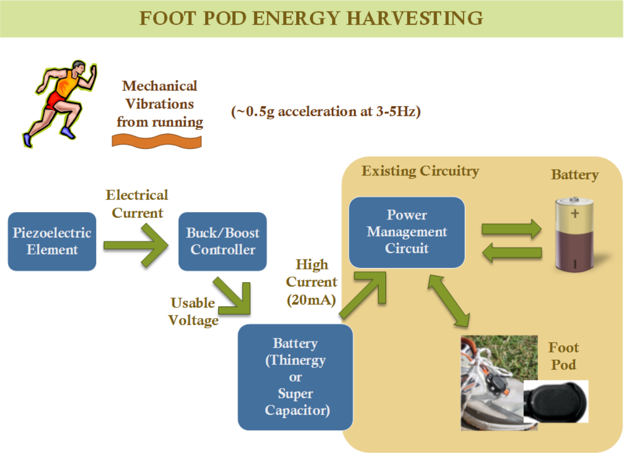
Concept Sketch

Heart Rate Monitor Energy Harvester



Concept Sketch

Foot Pod Energy Harvester



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The Team

Delegation of tasks

Subgroups were formed to develop two energy harvesting prototypes simultaneously

- Thermoelectric (Heart Rate Monitor) Group
  - Jeramie Vens
  - Catherine Homan
  - Allison Sapienza
- Electromechanical (Foot Pod) Group
  - Tyler Chenhall
  - Rebekah Dejmal
  - Omer Vejzovic

Outline

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Constraints and Requirements

- Supply at least 10% of the power consumed by a device and fully power any added circuitry
- Interface to the latest device through existing circuitry
- Size must be smaller than a deck of cards and weigh less than 100 grams
- Operational in a variety of exercise scenarios
  - Fitness activities
  - Diverse environmental conditions
  - Different users
- Prototype cost less than $50
  - Garmin's Economies of Scale should reduce the commercial cost

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Existing Energy Harvesting Products

- Luxury solar watches
- Intermittent transmitters (remotes, wireless sensors)
- Numerous research prototypes
- Typical applications are low power or have plenty of space for harvesting

Viability Surveys

Results

- People surveyed generally would pay more for a heart rate monitor than a foot pod overall
- On average, people were willing to spend $23.98 more for an energy harvesting heart rate monitor, and $19.45 more for a foot pod
- Of people willing to spend over $40 on a heart rate monitor, they are willing to spend $36.39 more for energy harvesting
- Of people willing to spend over $40 on a foot pod, they are willing to spend $26.82 more for energy harvesting
- More information can be found in Appendix G of the final document.

Details

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Energy Harvesting Research

- Thermal energy
  - **Seebeck Effect**
- Mechanical energy
  - **Piezoelectric material**
  - Faraday's Law
- Electromagnetic energy
  - Radio frequency
  - Solar radiation

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Outline

1. Background
   - Problem Statement
   - Concept Sketch
   - Team
2. Project Plan
   - Requirements
   - Research
3. System Design and Testing
   - Power Selection Circuitry
   - Thermoelectric Heart Rate Monitor
   - Mechanical Electric Foot Pod

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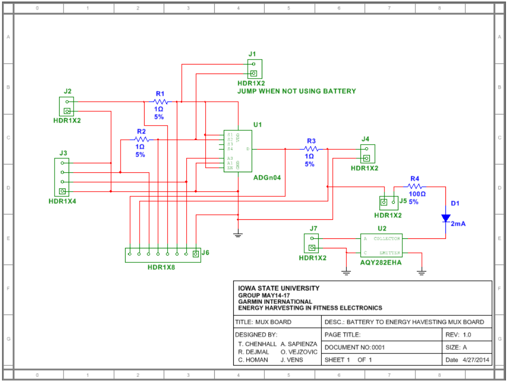
Detailed Design

Revision II: Schematic

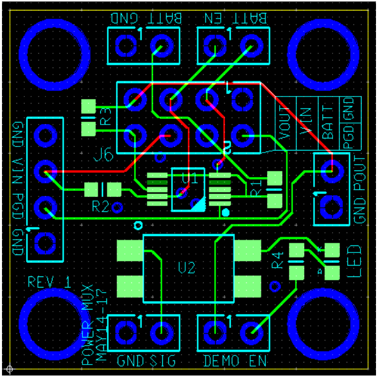


- Current measurement nodes
- Power multiplexer
- Simulated load and indicator
- Total price of $5.04

For more details, see Section 5.3 of Final Document

Detailed Design

Revision II: Printed Circuit Board



For more details, see Appendix A of Final Document

- PCB of the selection and display board
- Size: 1"×1"
- Input: Energy connector from either energy harvesting board (V_{out}, P_{good}, *Ground*), Battery, Modulation Signal
- Output: P_{out}

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Detailed Design

MATLAB Calculations

- Used MATLAB to calculate various capacitor values
- Found standard values within acceptable ranges
- Solved for efficiency and expected results
- Used these expected values during the testing phase

Excerpt from MATLAB Code

```
%% Step-Up Transformer
TransformerRation = 100; % 1:100
TransformerPrimaryDCResistance = 0.085; % ohms
TransformerSecondaryDCResistance = 205; % ohms
TransformerPrimaryInductance = 7.5e-6;  % Henry
TransformerSecondaryInductance = 75e-3; % Henry
PinC2_Cap = 33e-12;                     % Farad
f = 50000;                              % Hz
C2 = 1/((2*pi*f)^2*TransformerSecondaryInductance)-PinC2_Cap;       % Farad
C2 = 330e-12;                                                        % set this to standard value similar to calc value
f = 1/(2*pi*sqrt(TransformerSecondaryInductance*(PinC2_Cap+C2)));   % Actuall Frequency (Hz). Goal: 10kHz-100kHz

%% C1 Capacitor
C1 = 1e-9; % Farad (recomended for 1:100 transformer

%% Squegging Resistor
R_squeg = 499000; % ohms (recommended for a C2=330pF)

%% Vout and VSTORE Capacitor
Cout_min = I_burst*t_pulse/(Vout*droop/100);  % Farad
Cout_max = 100*(I_charge - I_Q)/(f_pulse*Vout*droop);
I_charge_min = I_burst*f_pulse*t_pulse+I_Q
Cout = 185e-6;                                                      % pick this based on Cout_min and Cout_max
Cstore_min = (6e-6+I_Q+I_LDO+(I_burst*t_pulse*f_pulse))*T_store/(5.25-Vout)
Cstore = 100e-3; % F : Based on Cstore_min.
%% Turn-on time
t_LDO = 2.2*Cout/(I_charge - I_LDO)
t_vout = (3*Cstore)/(I_charge - I_Q - I_LDO)/60

T_store_actual = Cstore*(5.25-Vout)/(6e-6+I_Q+I_LDO+(I_burst*t_pulse*f_pulse))/60
```

For more details, see Appendix D of Final Document

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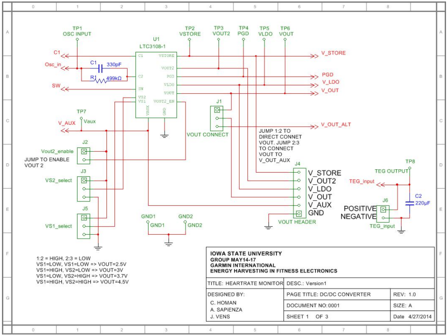
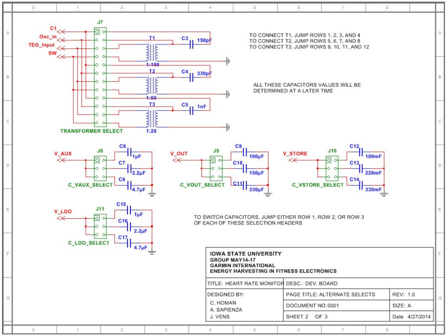
Detailed Design

Revision I: Schematics

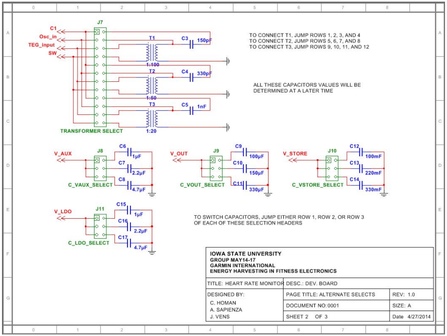


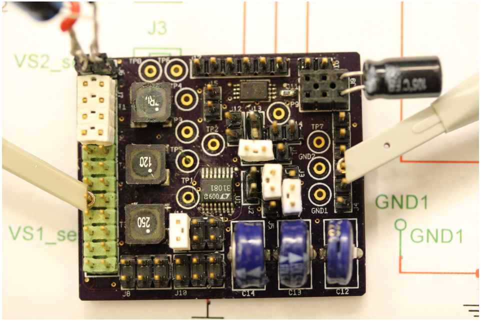


For more details, see Section 5.1 of Final Document

Detailed Design

Revision I: Board





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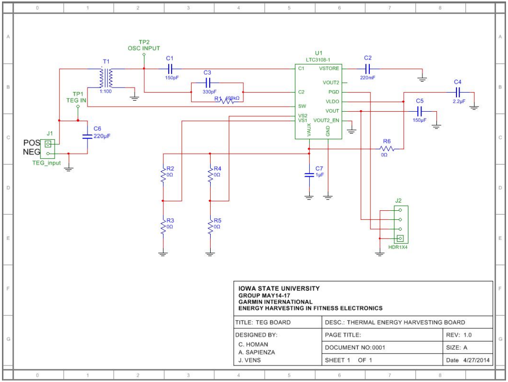
Detailed Design

Revision II: Schematic

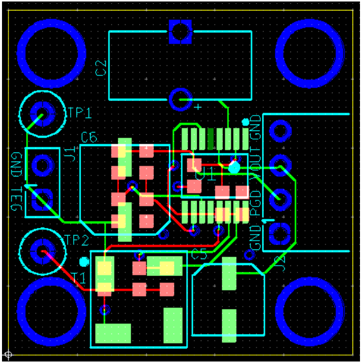


For more details, see Section 5.1 of Final Document

- The TEG harvesting circuit
- LTC DC-DC converter and voltage regulator
- Energy storage via super capacitor
- The 20mm TEG costs \$16.00
- The board and other parts cost \$14.16

Detailed Design

Revision II: Printed Circuit Board



For more details, see Appendix A of Final Document

- PCB of the TEG board
- Size: 1"×1"
- Input: TEG Connector
- Output: Energy Connector (V_{out}, P_{good}, *Ground*)

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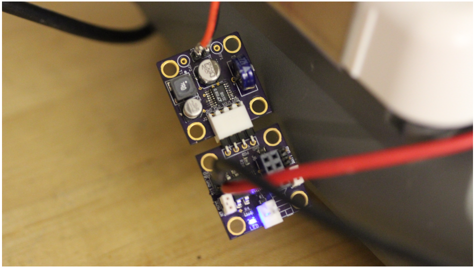
Demonstration

Demo

Revision II: Testing Method



For more details, see Section 6.1 of Final Document

- Connected to the power selection board for testing
- Used with a 5mA load at 4Hz frequency and 2ms duty cycle
- Able to drive load with an ideal temperature difference between skin and ambient air

Energy Calculations

- Charge stored in the super capacitor
  - $C = 220\text{mF}, V = 5.25\text{V}$
  - $C = \frac{Q}{V} \Rightarrow Q = CV = (220\text{mF})(5.25\text{V}) = 1.155\text{C}$
- Energy stored in the super capacitor
  - $W = \frac{1}{2}QV = \frac{1}{2}(1.115\text{C})(5.25\text{V}) = \mathbf{3.032J}$
- Therefore, when removed from ambient energy the circuit can continue to provide 3J of energy

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Detailed Design

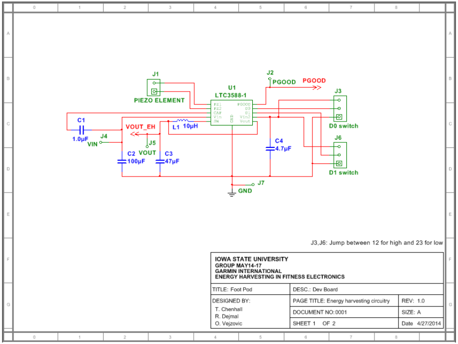
Initial Tests and Calculations

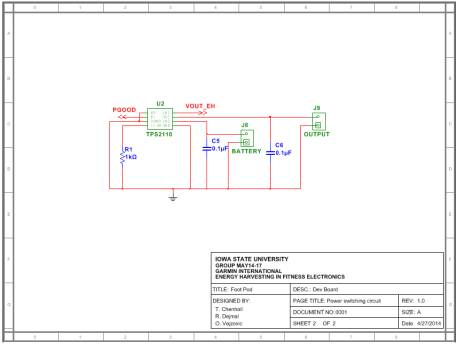
- Foot pod power was estimated by monitoring voltage across a series resistor
- Several mechanical harvesters were characterized by their average power output (Mide V21BL, below)

Load (kΩ)	5.0g (μW)	7.5g (μW)	10.0g (μW)	12.5g (μW)	15.0g (μW)
4.7	-	-	38.39	50.86	72.37
10	66.10	79.74	56.85	103.25	173.79
47	170.52	246.25	158.92	**448.45**	**555.14**
100	178.42	348.81	195.36	**532.90**	**621.73**
470	71.53	118.00	242.78	301.80	296.46
1000	40.28	58.43	92.16	126.11	-

Detailed Design

Revision I: Schematics





For more details, see Section 5.2 of Final Document

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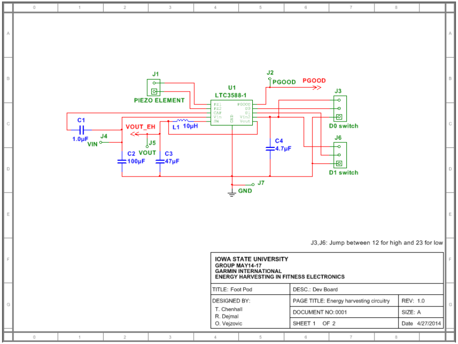
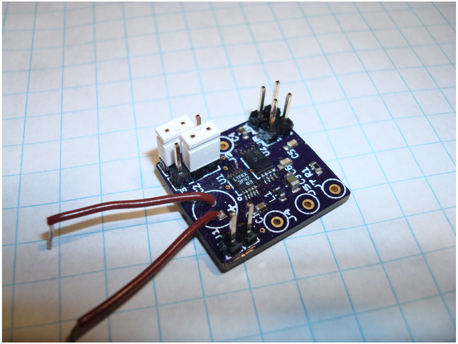
Detailed Design

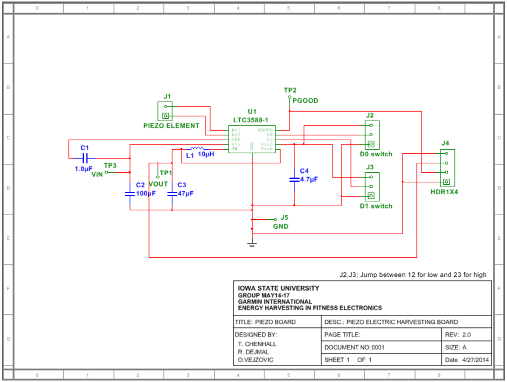
Revision I: Board





Detailed Design

Revision II: Schematic

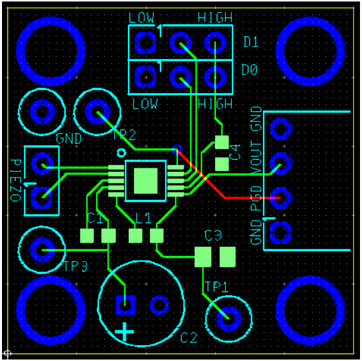


- Piezoelectric element
- LTC buck converter
- Mide's V21BL costs $65.00
- The board and other parts cost $9.99

For more details, see Section 5.2 of Final Document

Detailed Design

Revision II: Printed Circuit Board



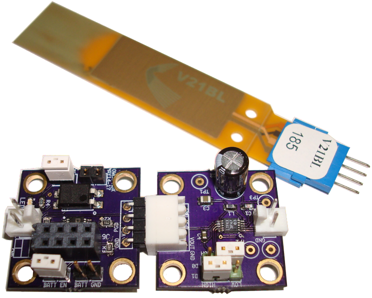
For more details, see Appendix A of Final Document

- PCB of the Piezo board
- Size: 1"×1"
- Input: Piezo element
- Output: Energy Connector (V_{out}, P_{good}, *Ground*)

Demonstration

Demo

Revision II: Testing Method



For more details, see Section 6.2 of Final Document

- The board plugs into the power selection board
- To verify robust operation, tests were performed with the device attached to an individual during typical exercise activities
- For the mechanical group, tests included various running surfaces, stride cadences, and cantilever tip masses

Summary

Project Status

- Current and power consumption has been measured for Garmin's fitness devices
- Revision I prototypes were assembled, tested, and used to develop circuit improvements
- Revision II prototypes were designed and created
- Extensive testing was conducted on the revision II boards
- Energy harvesting research and prototype information was compiled into a final document
- Deliver documentation and prototypes to Garmin and present findings at their location in Olathe, KS

Recommendations

We do not recommend either solution.

- Thermoelectric
  - Size
  - Temperature requirement
- Piezoelectric
  - Size
  - Cost

Questions

Any Questions?

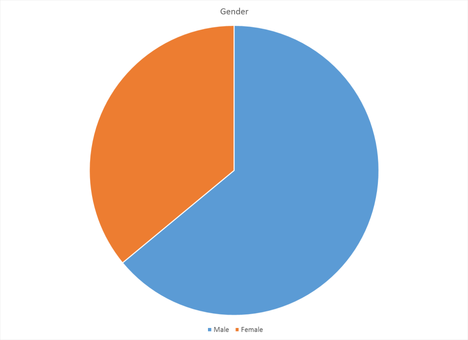
Survey Questions

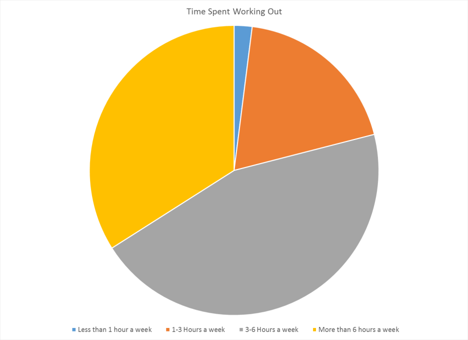
To evaluate market interest in an energy harvesting product, surveys were distributed at State Gym, an Iowa DOT office, and several other locations

Survey Questions:

- Gender
- Amount of time spent exercising each week
- Maximum acceptable price of a battery powered HRM
- Would you pay more for a battery-less HRM?
- Maximum acceptable price of a battery powered foot pod
- Would you pay more for a battery-less foot pod?

Survey Questions





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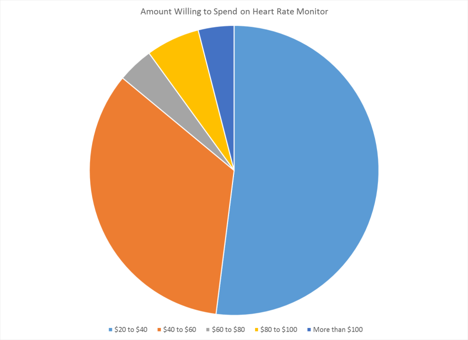
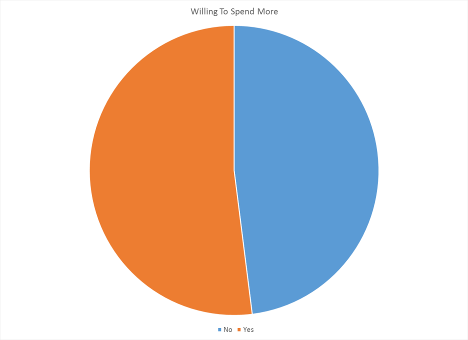
Survey Questions

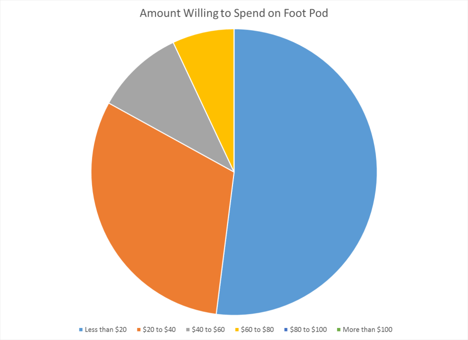
Heart Rate Monitor

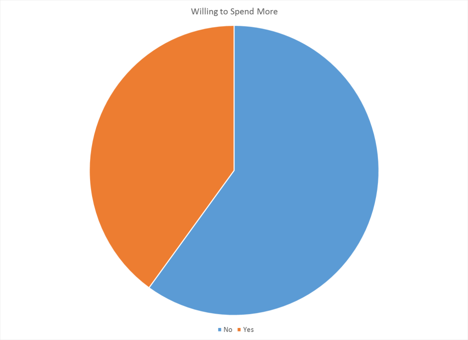




Survey Questions

Foot Pod





Return

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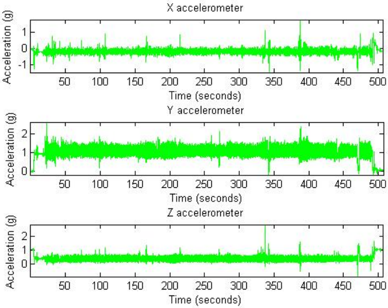
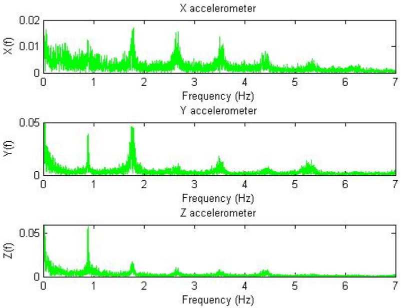
Walking

Time



Frequency



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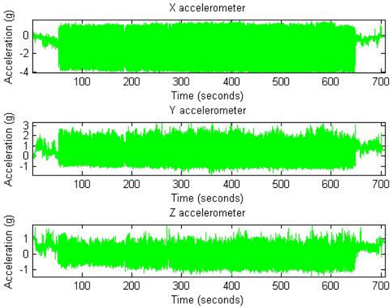
Running

Time



Frequency