Kinetic Energy Availability Studies
Mina Cong, Maria Gorlatova, Gil Zussman
Department of Electrical Engineering, Columbia University, New York, NY

Abstract
Energy-Harvesting Active Networked Tags (EnHANTS) are small, flexible, and energetically self-reliant devices that can be attached to traditionally non-networked objects. EnHANTS will enable the Internet of Things (IoT) by providing infrastructure for novel tracking applications such as locating misplaced items and continuous peer-based monitoring of objects. EnHANTS will be powered by light and motion harvested energy, the latter of which will be examined here.

Methods
• SparkFun Electronics ADXL345 accelerometer board: +/-16g resolution, sampled at 100Hz, analyzed in Matlab
• Subjects: myself, lab participants, and dataset of 40+ participants
• Activities: focus on periodic human motions Specific Activities: walk, jog, stairs, jump, rest, etc.
• Objects: write (pencil), read (book), open drawer, Day-Long: typical work day (office/home)

Human Walking Example

Energy Harvesters

Results – Specific Activities (25s – 3h)
• 40 participants, 7 activities:
  • Relaxing: ~55gW
  • Walking: 120-280gW - 155gW (shirt), 180gW (belt), 202gW (pants) less than double for Fast Walking
  • Stairs: 1.5-2x more power for downstairs than upstairs
  • Running: 612-813gW
  • Cycling: 41-52gW
  • Normal activities: ~1-2kW

• Correlations:
  • Subjects: strong positive height to weight correlation (p=0.7, p<0.001)
  • More power: short people and light people (more steps per time interval).
  • Age correlation was found.

Results – Objects
• Power: <40gW
  • Less periodic, mechanical dampers, ...
• Shaking (emergency / quick recharge):
  • ~10-25x more power than walking
• Stairs: 1.5-2x more power for downstairs than upstairs
• Running: 612-813gW
• Cycling: 41-52gW
• Normal activities: ~1-2kW

Conclusions
• Studied motion patterns & energy availability (focused on humans over objects) - optimized energy (harvester, placement, activity duration, ...)
• Everyday human activities have the potential to power our rechargeable, wireless sensor systems.
• Energy availability correlates to human factors (ex: height and weight)
• Target specific groups to optimize results
(ex: different harvesters in different cloth sizes)

Results – Day-Long (6h – 11h)
• Coordinated Lab Group Study: instruct, analyze, & document 5 participants, >200 hours, 25 total days
• Results: >95% energy collected during 4-7% of day
• Dominant frequency: 1.92 – 2.8 Hz
• Power: comfortably send data at >1Kb/s

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Contact: mc3415@columbia.edu
Website: enhants.ee.columbia.edu

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Table 1: Nomenclature.

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<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>m Harvester proof mass</td>
<td>[kg]</td>
<td></td>
</tr>
<tr>
<td>ZL Harvester proof mass displacement limit</td>
<td>[m]</td>
<td></td>
</tr>
<tr>
<td>k</td>
<td></td>
<td></td>
</tr>
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<tr>
<td>Q</td>
<td>Q = 3.87</td>
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</tbody>
</table>

40-Participant Study

Internet of Things (IoT) Application ex: search for keys through a network of EnHANTS attached to objects

Future Work
• Extensive dataset: study human variations, daily routine patterns, ... (publically available soon)
• Additional activities + more participants → more correlations
• Combine light-energy harvesting with motion-energy harvesting
• Hardware & algorithms

Acceleration → Power
Model implemented in Matlab/SIMULINK

Calculated ideal harvester sets:

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency (kHz)</th>
<th>Q</th>
<th>b</th>
<th>h</th>
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<td>2.25</td>
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<td>Speed</td>
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