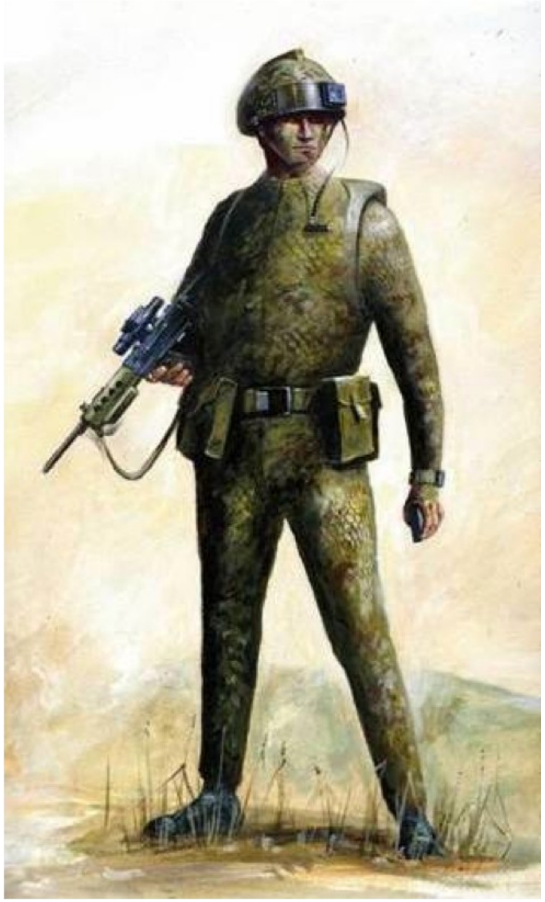

Mobile Energy Harvesting Systems

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University of Leeds

[dstl]

EPSRC

The Consortium

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- Neil Sims – University of Sheffield
- Andrew Bell – University of Leeds
- Meiling Zhu – Cranfield University
- Xunli Zhang – Southampton University
- Stephen Burrow – Bristol University
- Stephen Fitz – Essex University

"Battery-Free Soldier" Initiative

[dstl] EPSRC

The Problem

British foot soldiers typically carry packs of between 45 and 75 kg when on patrol.

Up to 20 kg of this can be batteries.

Batteries also represent a significant problem in supply logistics.

Can energy harvesting techniques help mitigate these problems ?

Aim

- Design, develop and demonstrate modular kinetic energy harvesting systems for the foot soldier
  - Piezo (lower risk) and microfluidic (higher risk) harvesting principles
  - Focus on user comfort and fatigue rather than maximum power output
  - Demonstrator based on stand-alone, self powered equipment (e.g. personal radio)

[dstl]

Four Power Sources

1. Burden displacement
2. Small proof-mass displacement
3. Knee articulation
4. Foot-fall

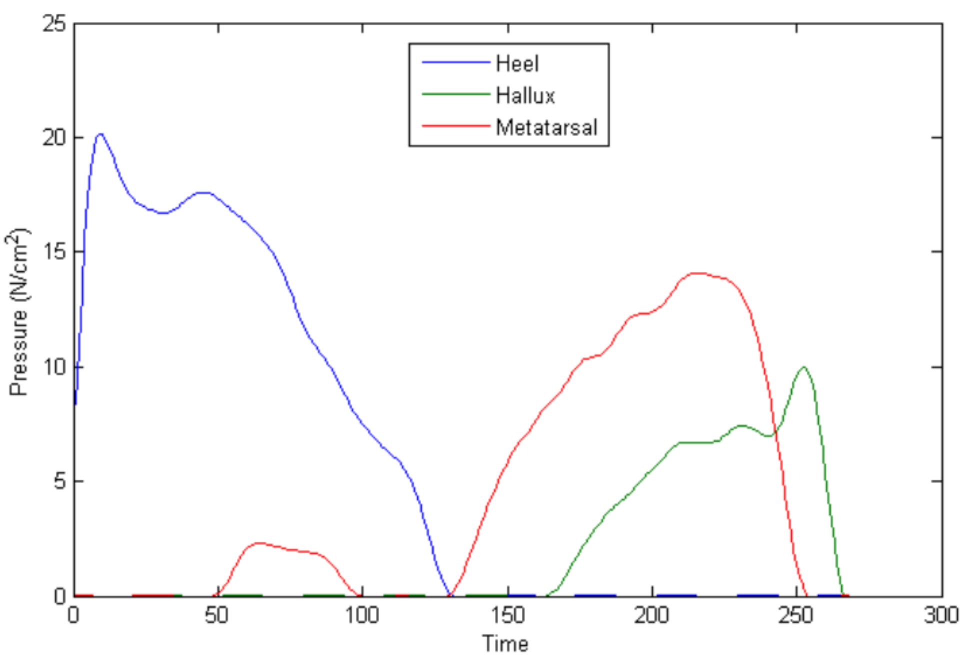
\+ Biomechanics

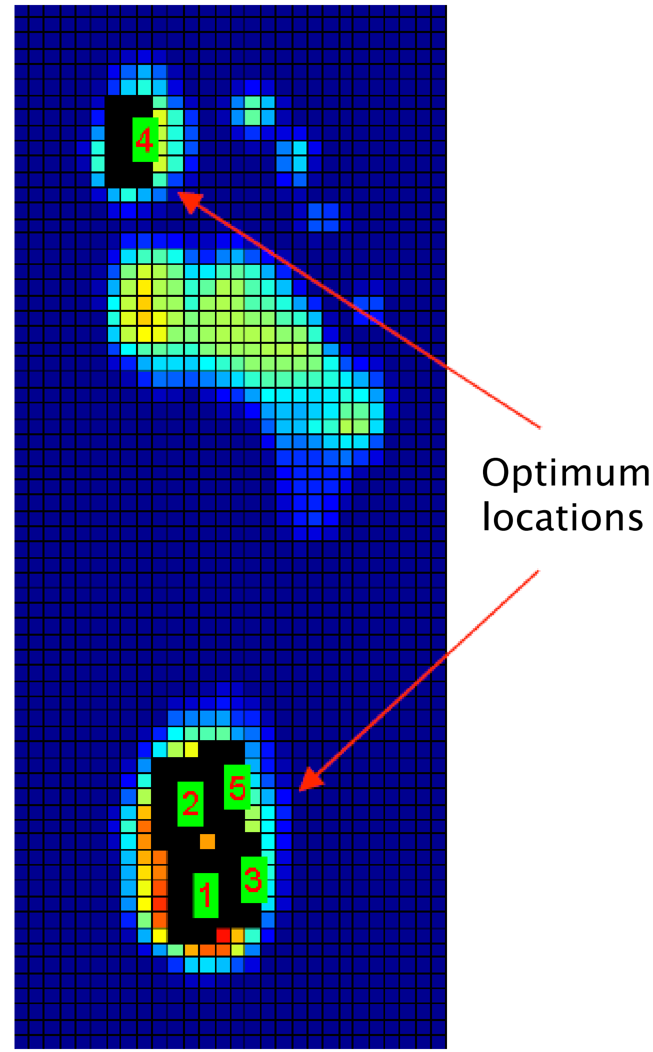
\+ Low power radio demonstrator

Biomechanics
Foot-fall Analysis

Facilitates transducer selection and positioning.

Highlights areas of potential discomfort.





Biomechanics
Motion Analysis

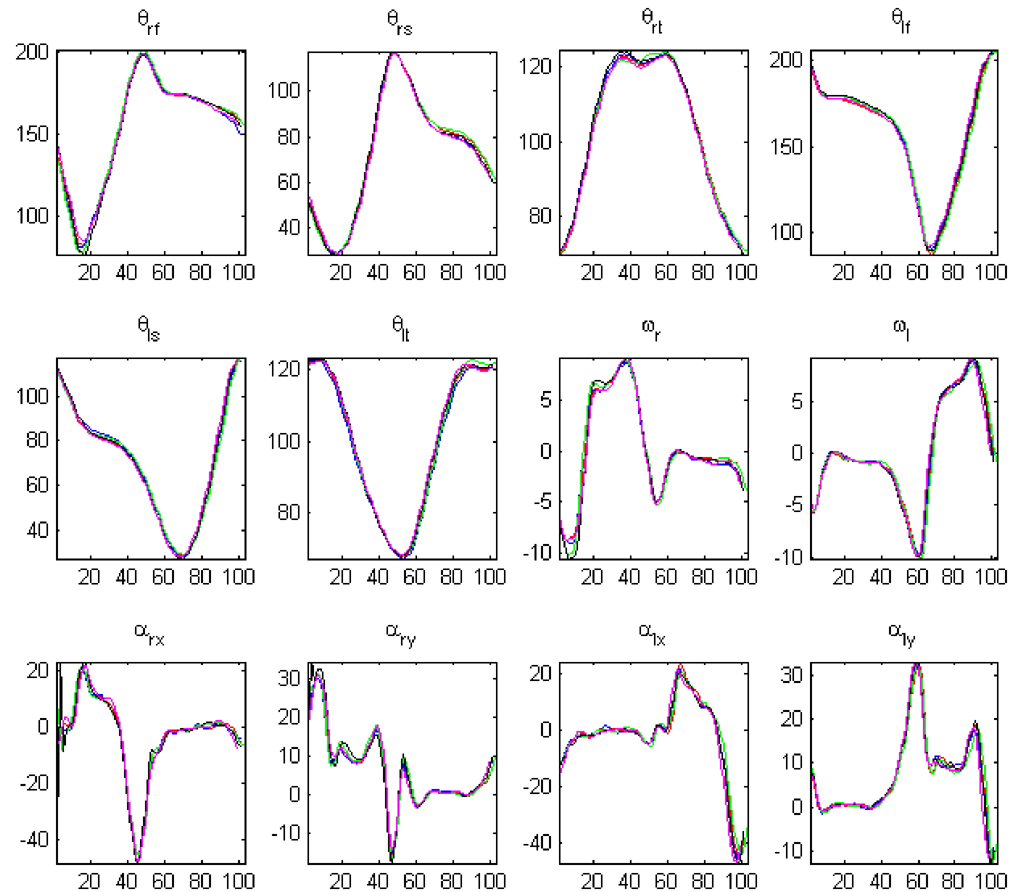
Facilitating design of harvesters employing joint articulation and self-contained proof-mass.

Joint Data:

- Ankle, Knee, Hip.
- Joint Angles.
- Angular Velocities and Accelerations.

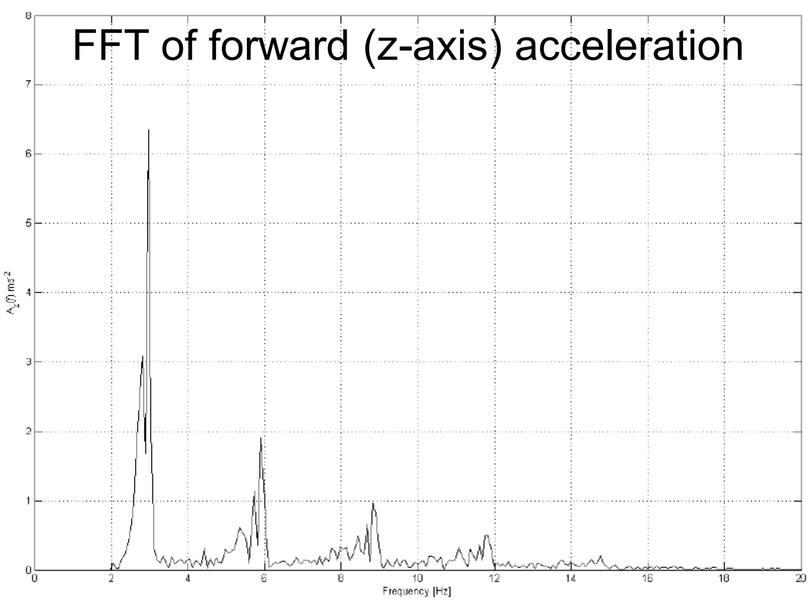
Segment Data:

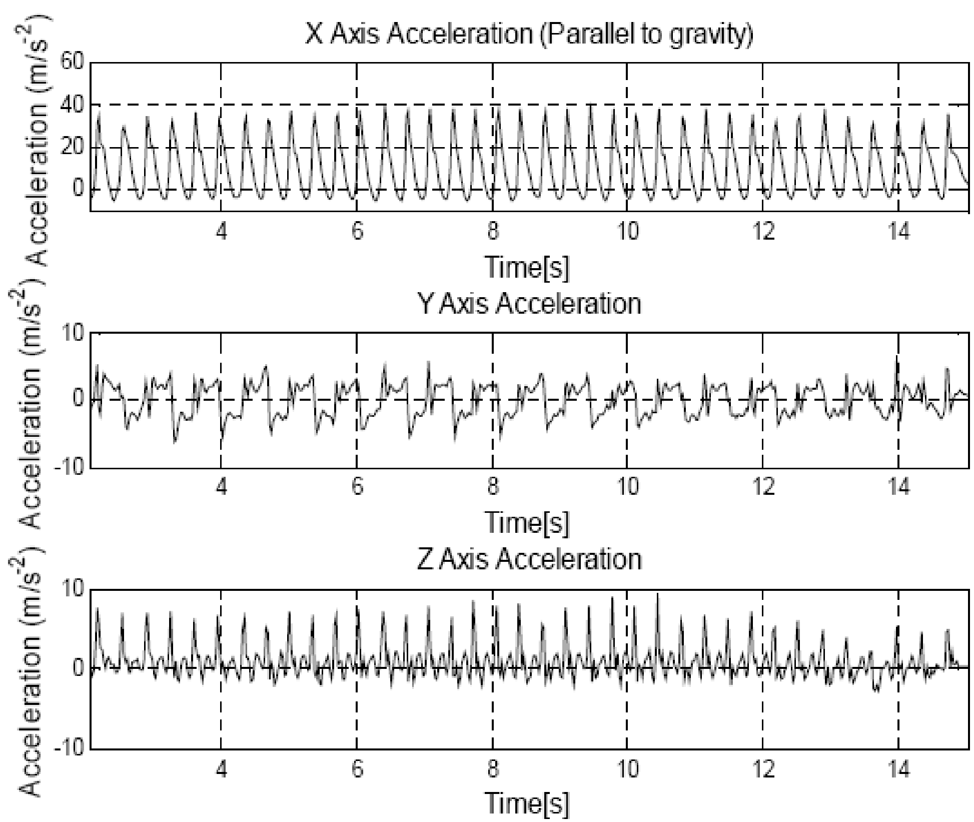
- Thigh, Shank, Foot.
- Proximal and Distal Positions.
- Proximal and Distal Velocities and Accelerations.



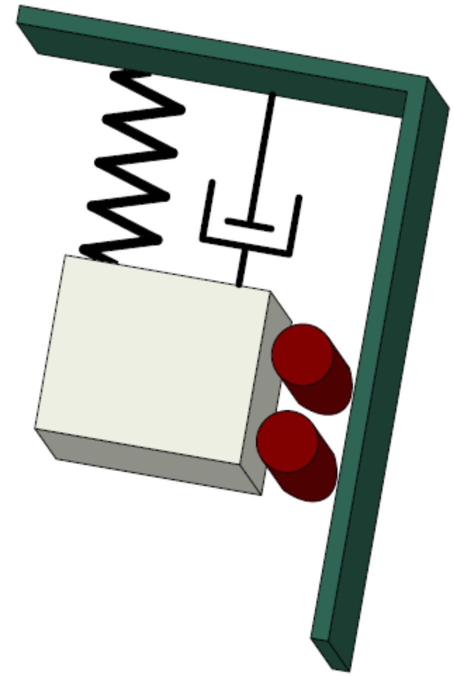
Biomechanics
Acceleration Analysis

Motion of rigid backpack frame whilst jogging

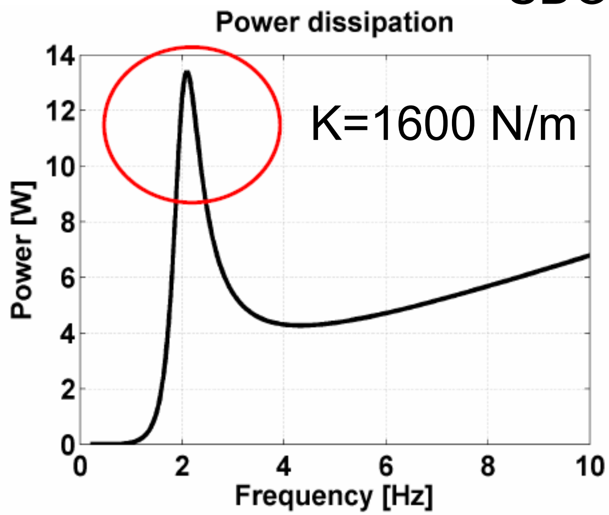


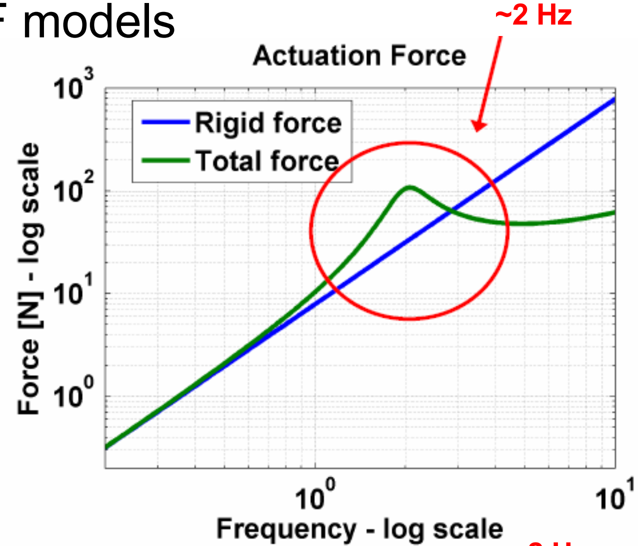


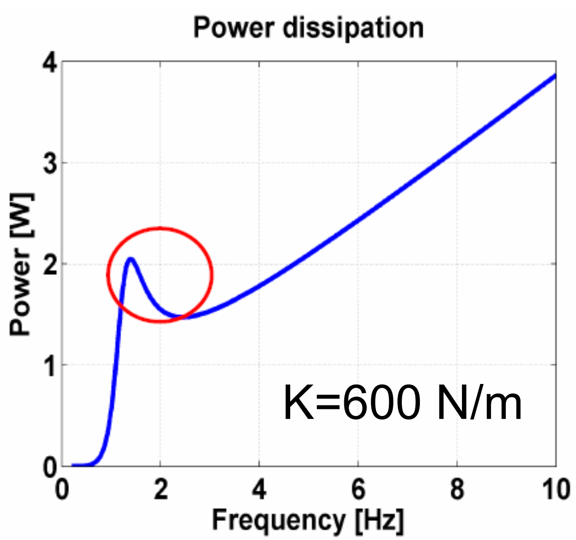
Back Pack Strategy

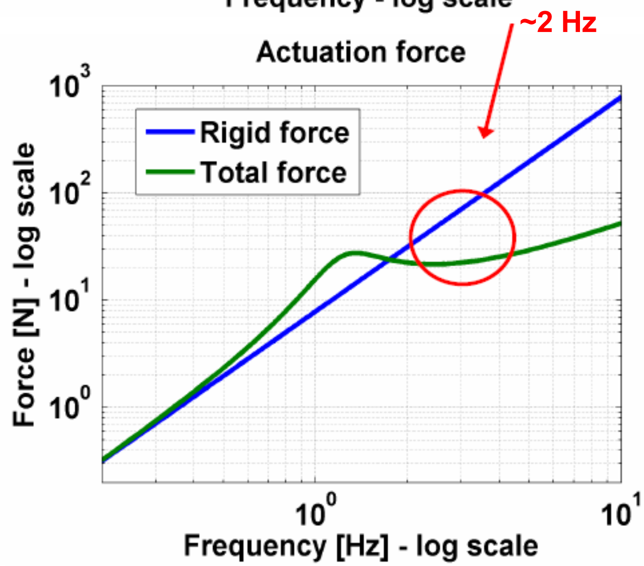


SDOF models



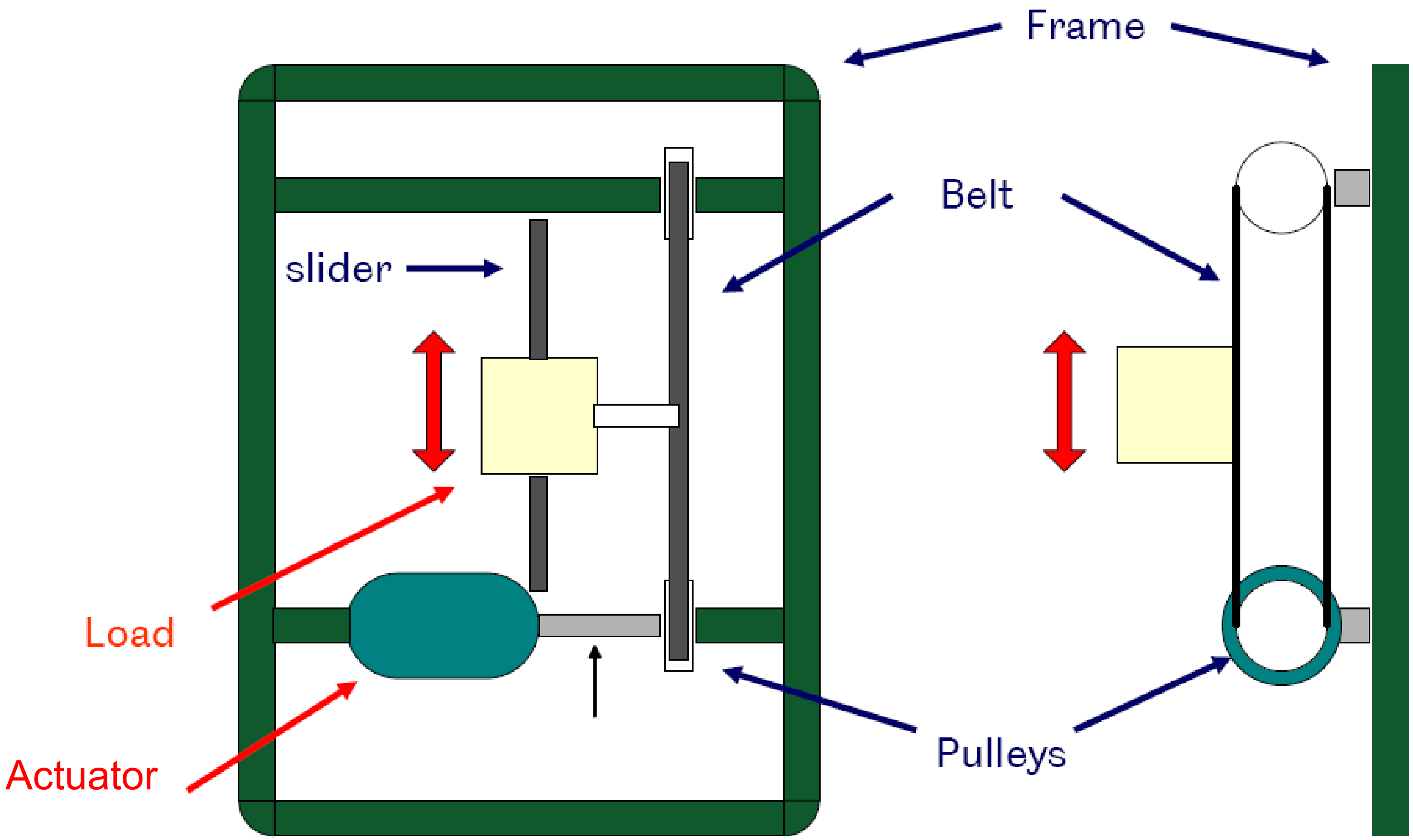






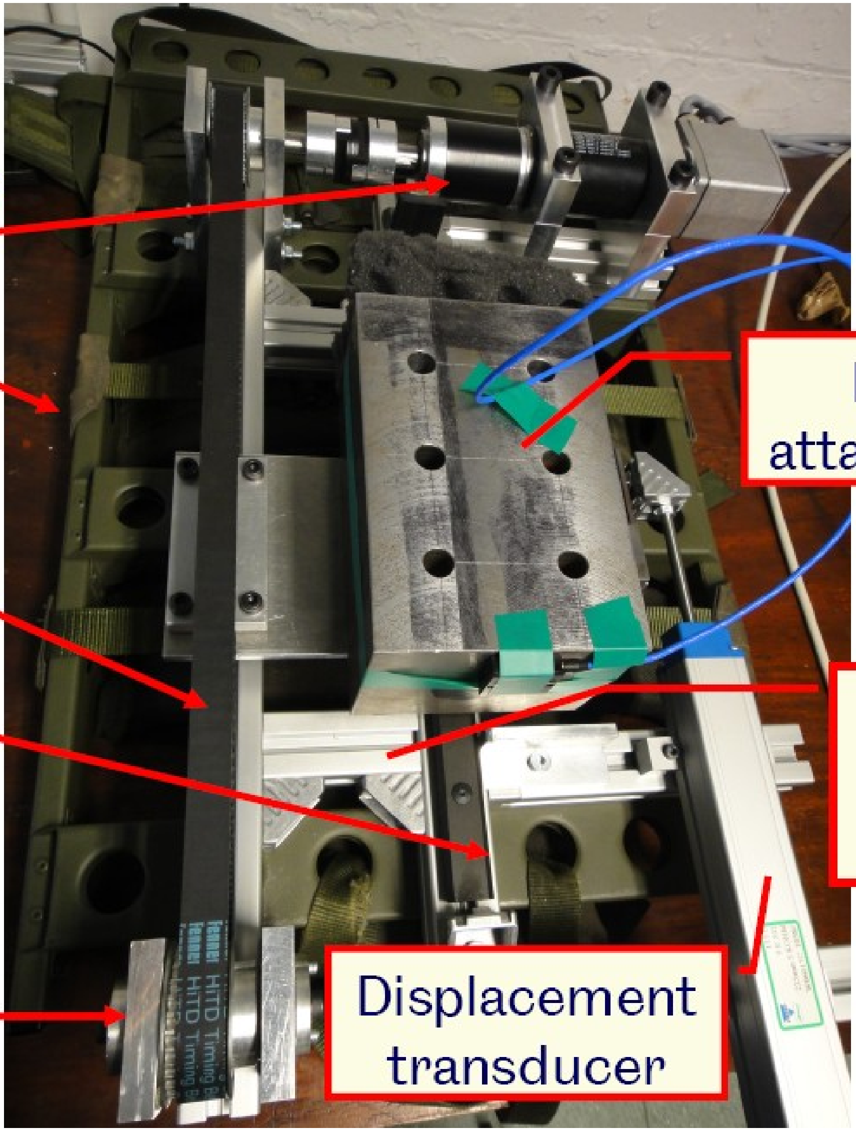
- Harvester appears as a viscous damper.
- For optimization studies, the harvester is replaced with and actuator to simulate spring & damper behaviour.
- Tune the power–comfort compromise

Back Pack
Test System



Viscous damper harvester emulated by motor

Actual system

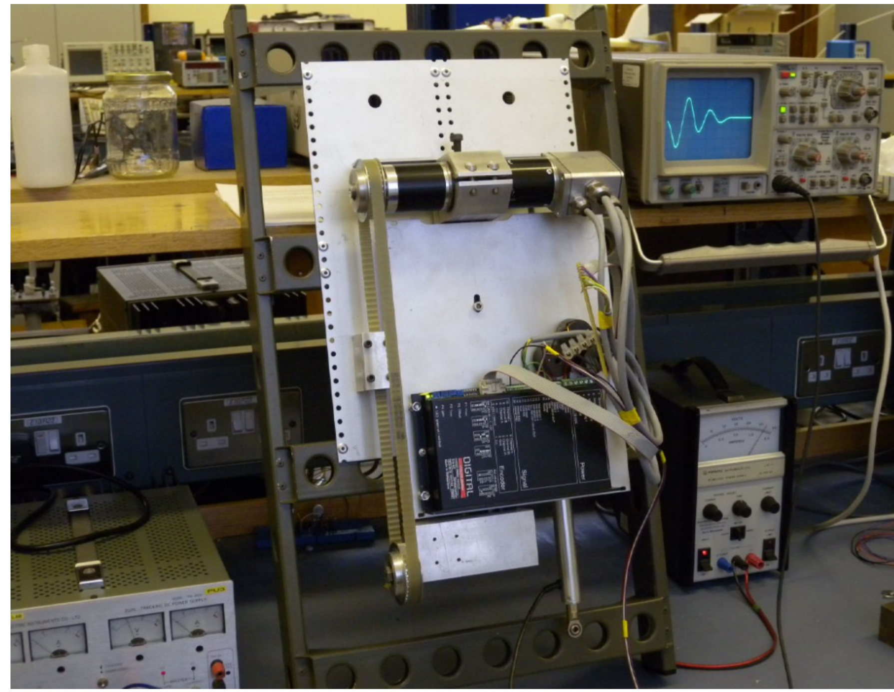


Back Pack
Test Protocol

- 6 –12 participants
- Walk on a treadmill carrying the backpack, while the mass moves vertically
- Measure treadmill reaction forces
- Questionnaire regarding the level of comfort
- Repeat the same with the mass not moving

Back-Pack
Adaptive Electronics

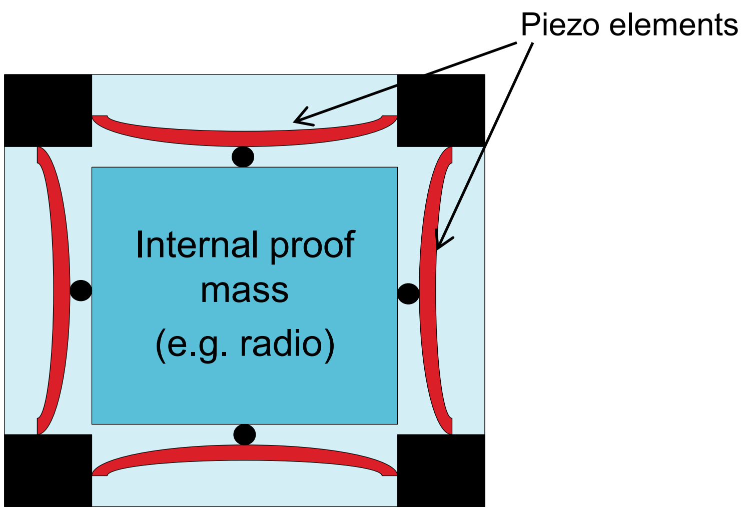
- Adaptive electronics being developed in a parallel rig for adaptive control of damper
- Simulink model of backpack energy harvester produced.
- Stiffness and damping controller implemented using analog circuit for preliminary tests.
- Controller migrated to d-SPACE.



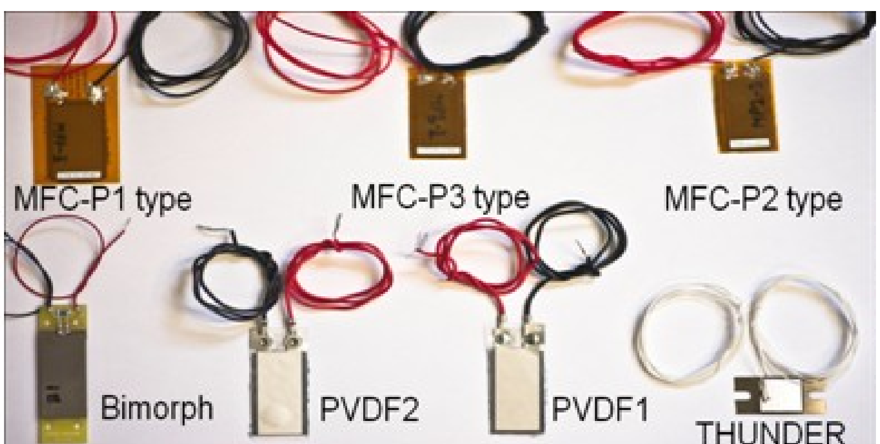
- Frictional losses in mechanism investigated, allowing parasitic damping to be reduced.

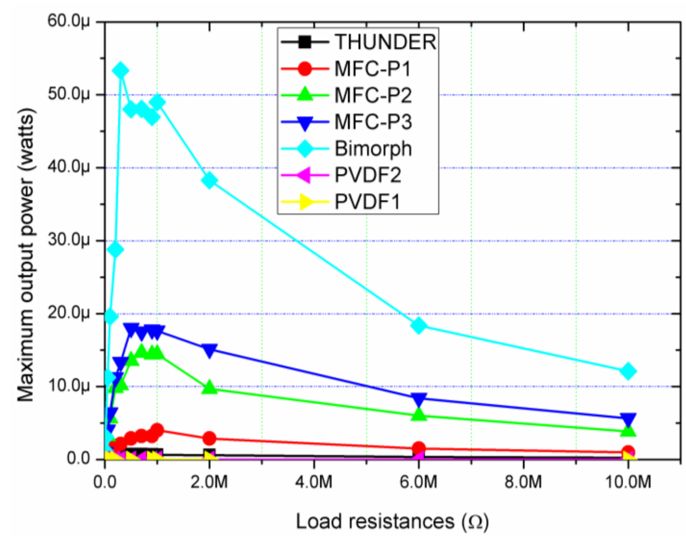
Small Proof Mass Transducer Characterization

Initial testing in context of "leaf-spring" suspension of internal proof mass

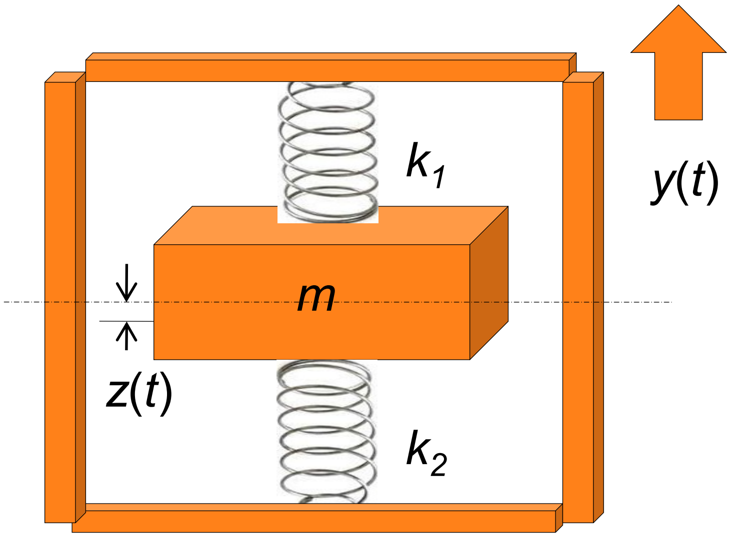


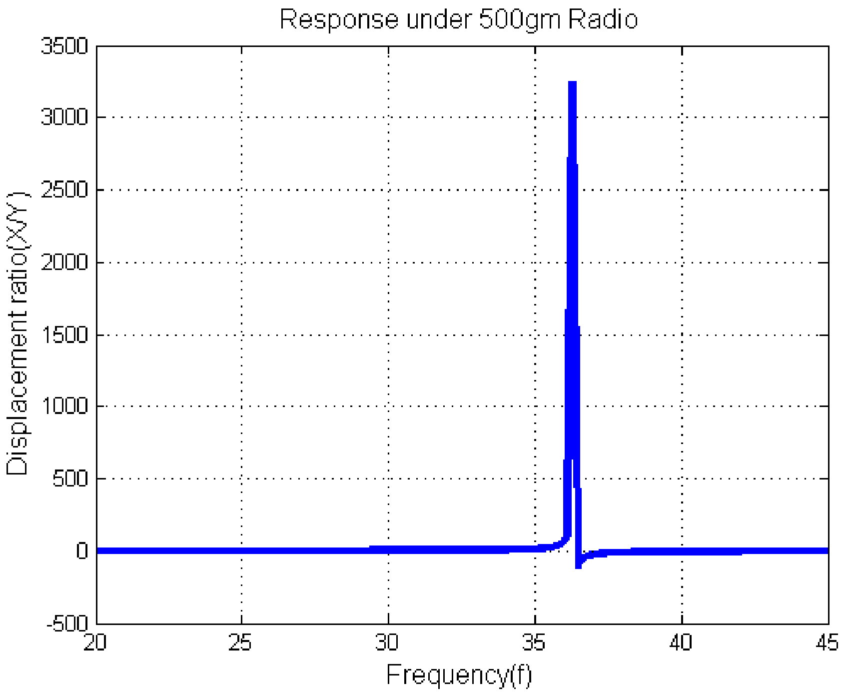
3-point bend testing of potential devices





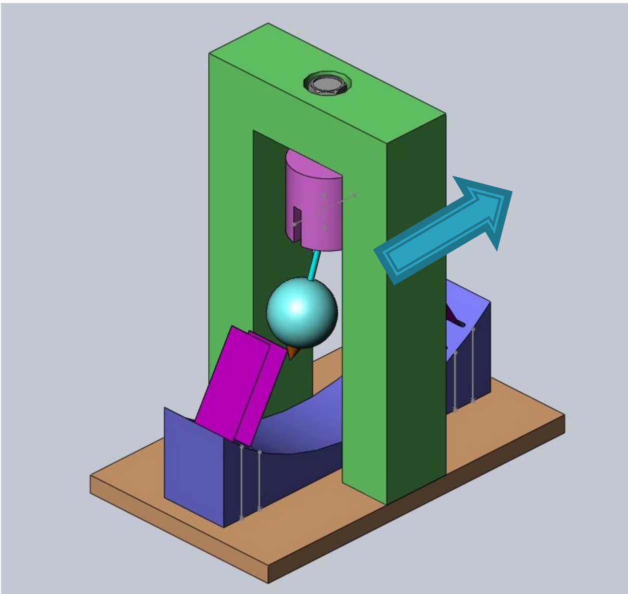
Small Proof Mass
Coupling to Gait

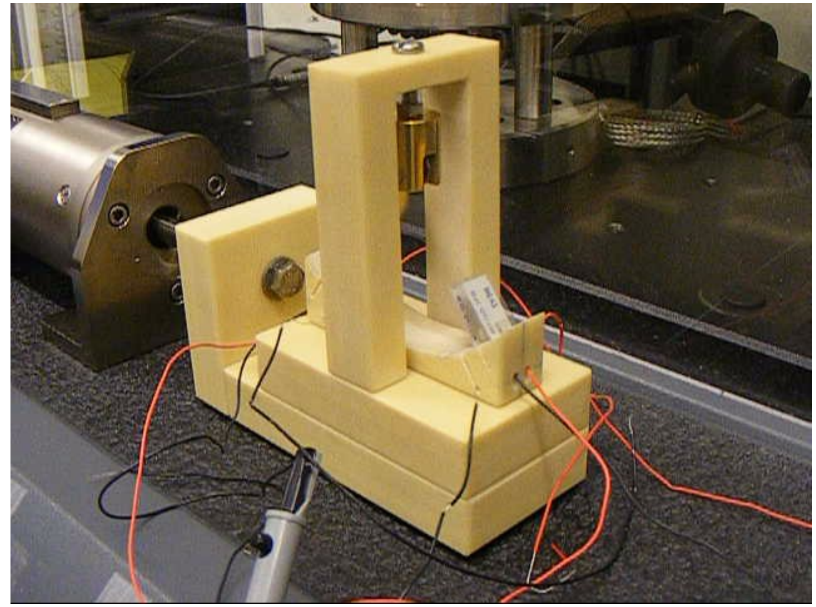


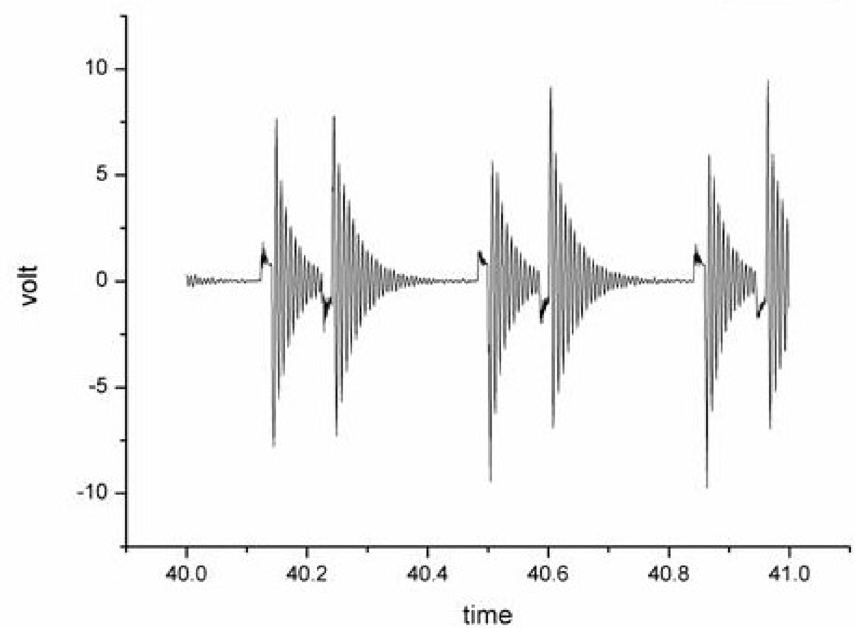


Given the compliance of the piezo elements and gait frequency, movement of soldier will not be coupled to proof mass.

Small Proof Mass
Frequency Bridging





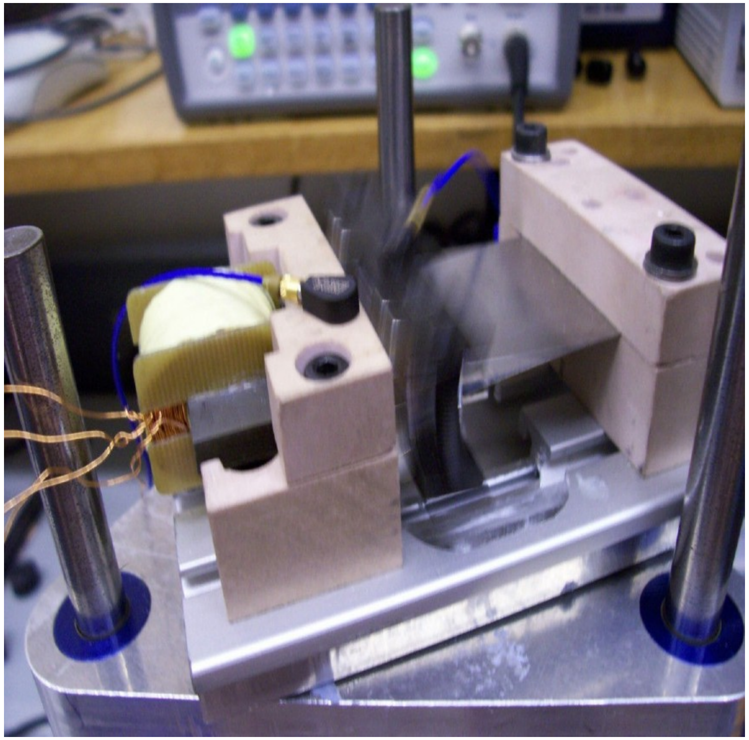


Now ~5 μW per element

Multiple elements +
multi-strike capability
→ >1 mW per unit

Small Proof Mass
Electromagnetic Design

- Non-linear energy harvester tested with triangular waveform to simulate impulsive jogging motion.
- Frequency up-conversion from 4 Hz to 20 Hz observed, and load power of 10 mW recorded.
- Further analysis required for full understanding of phenomenon.



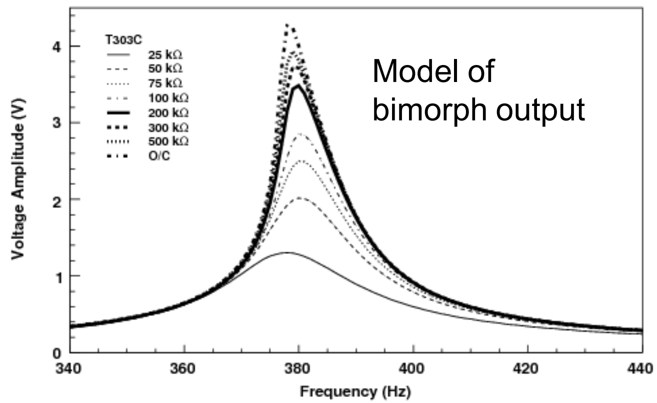
Knee Articulation
Objective

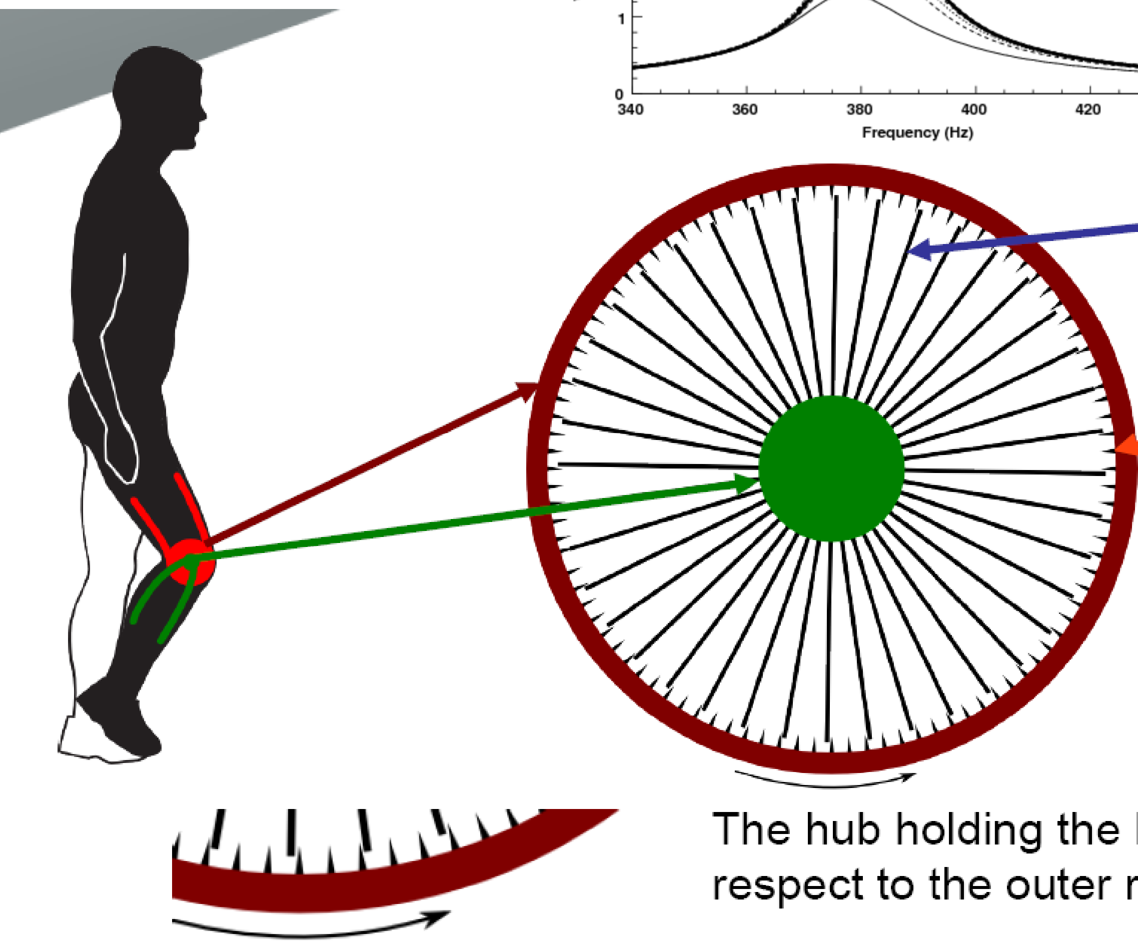
Current electromagnetic technology is bulky & heavy.

Target: low mass, high efficiency piezo-actuator system

Knee Articulation Concept

Advantages:
- low stiffness
- use of piezo at resonance

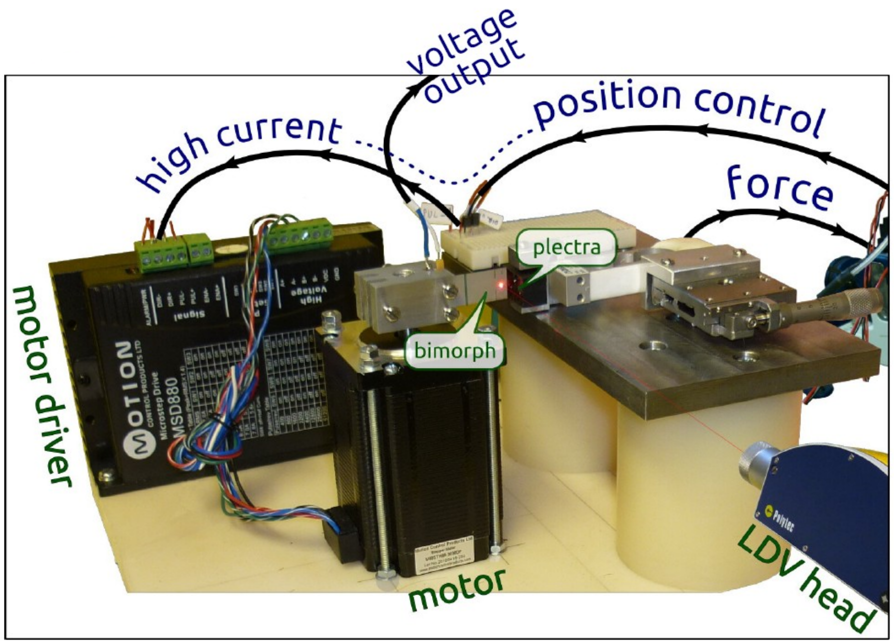


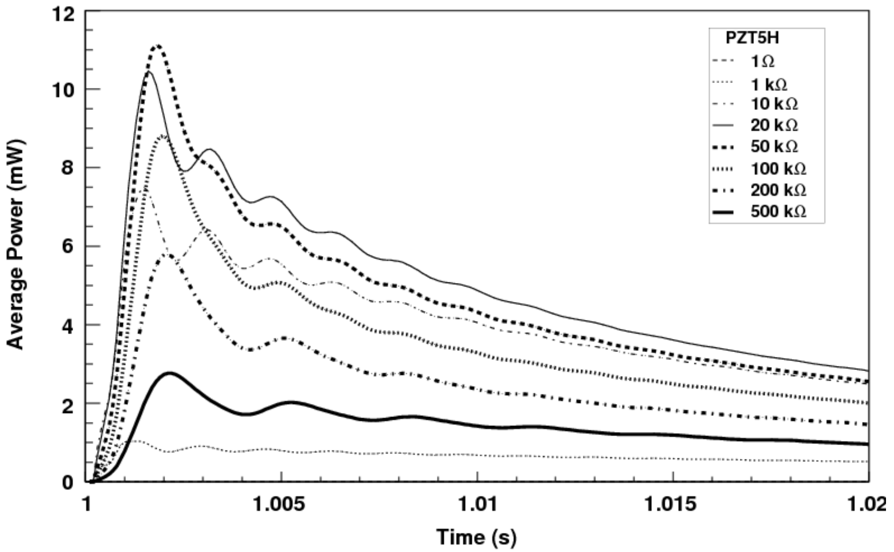


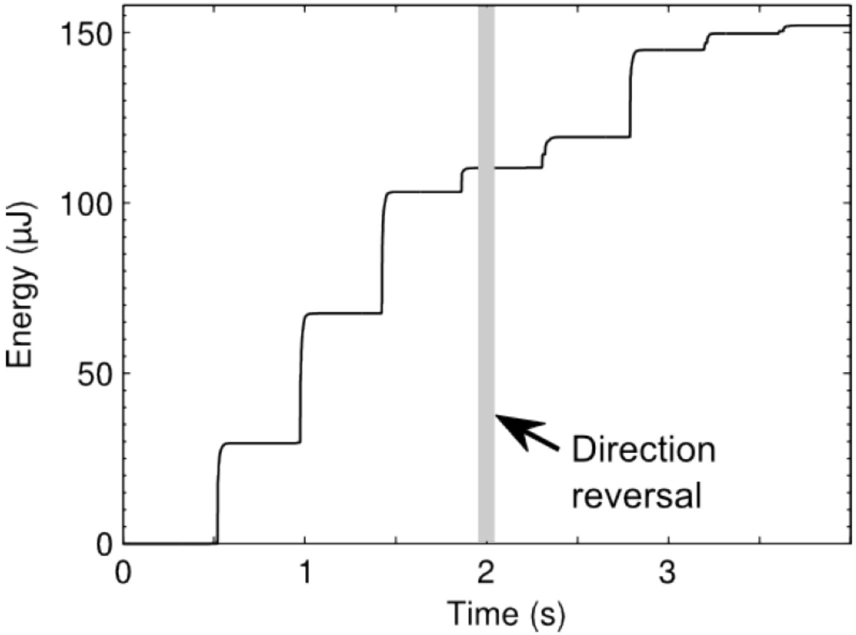
Piezoelectric bimorphs are plucked by the passing **plectra**

The hub holding the bimorphs rotates with respect to the outer ring, which carries the plectra

Knee Articulation
Proof of Concept

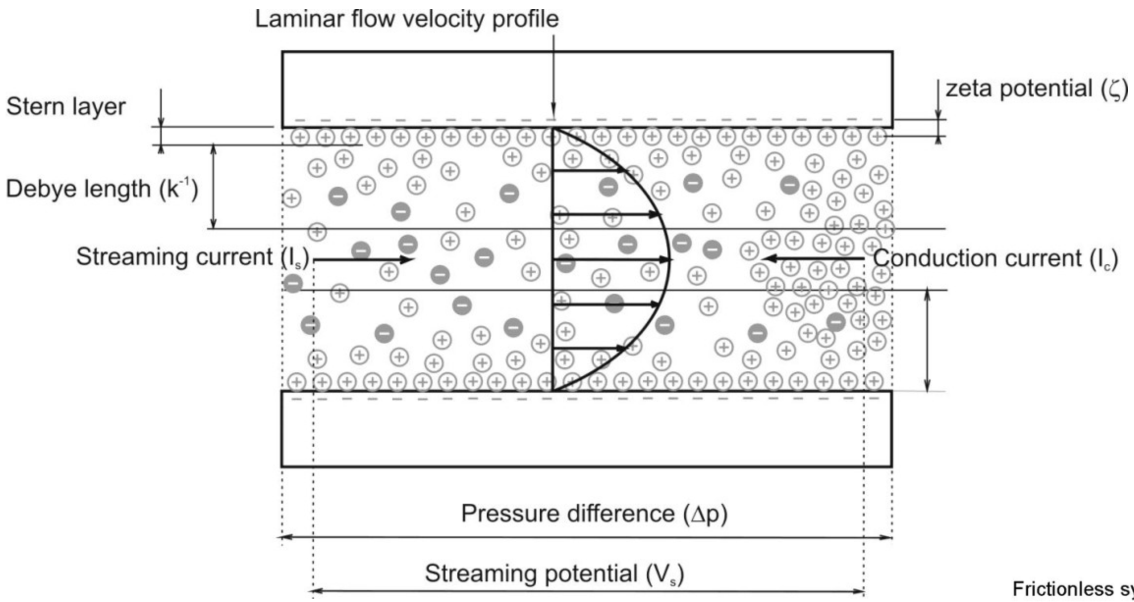




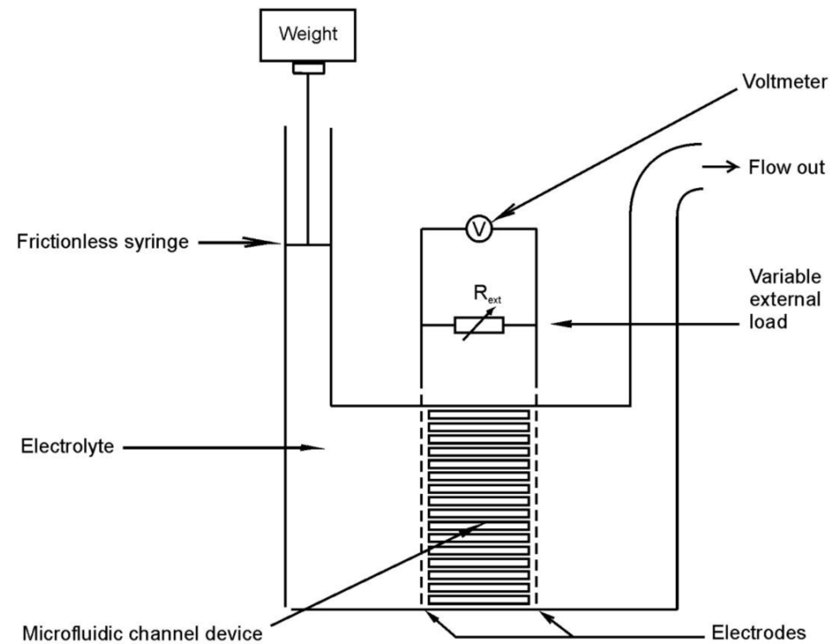


34 µJ per "pluck"

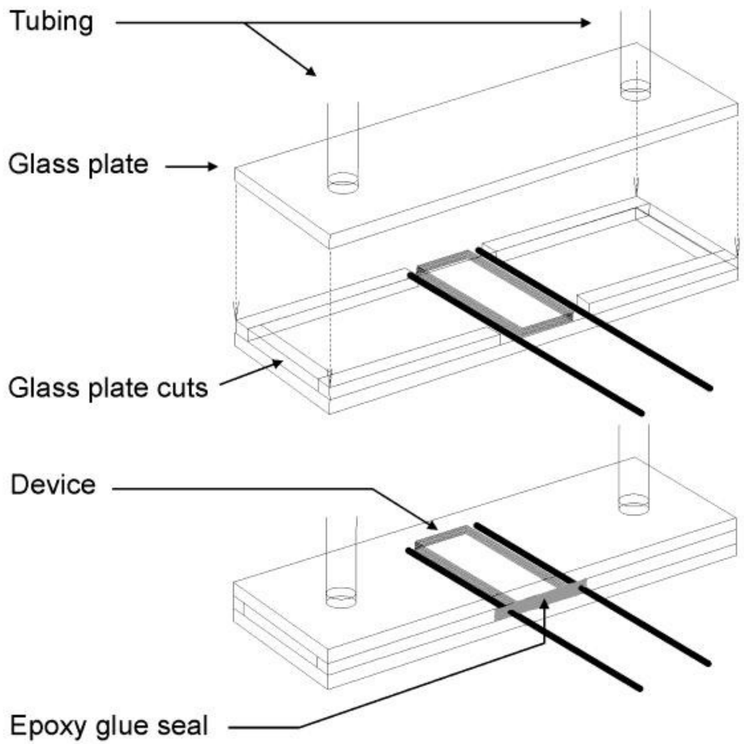
Footfall
Microfluidic Concept

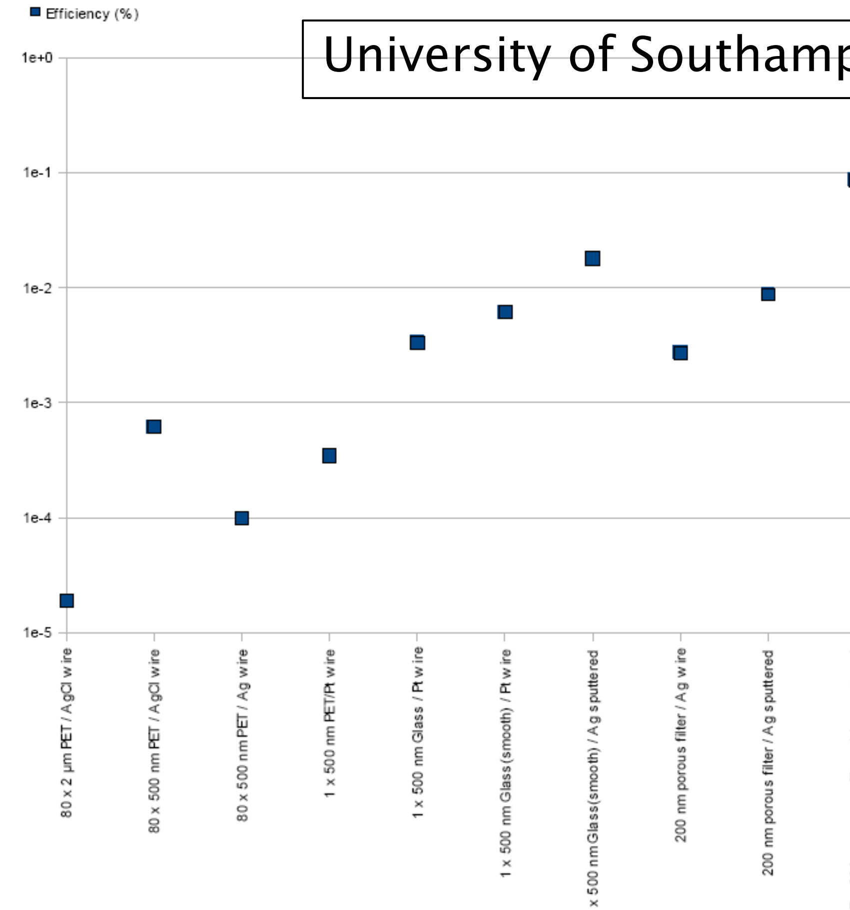


Microfluidic device
– work of pushing fluid through capillaries develops streaming potential and current in external circuit



Footfall
Device Test Data

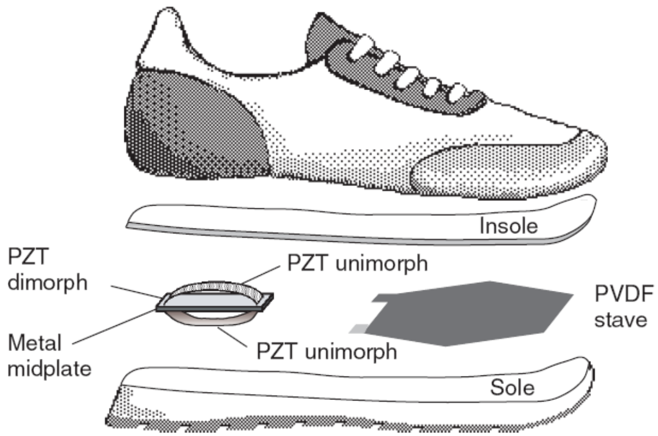




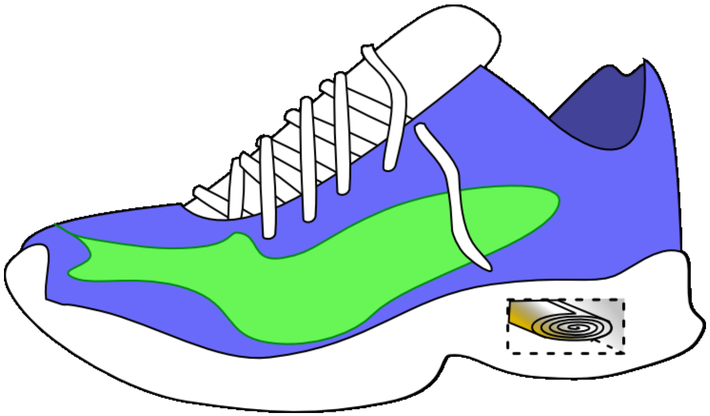
University of Southampton

- Maximum efficiency is 0.085%, at 120 nW output and 14 kPa pressure difference.
- At the likely operating conditions of 1 bar, the same device (2p coin size) would produce up to 6 µW.
- Increasing the efficiency to 1% would raise this output to 70 µW.

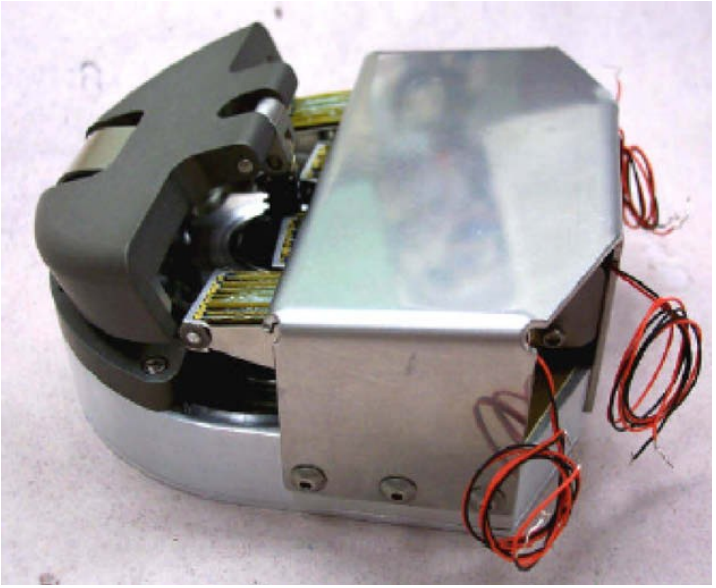
Footfall
Piezo Transducer



10 mW



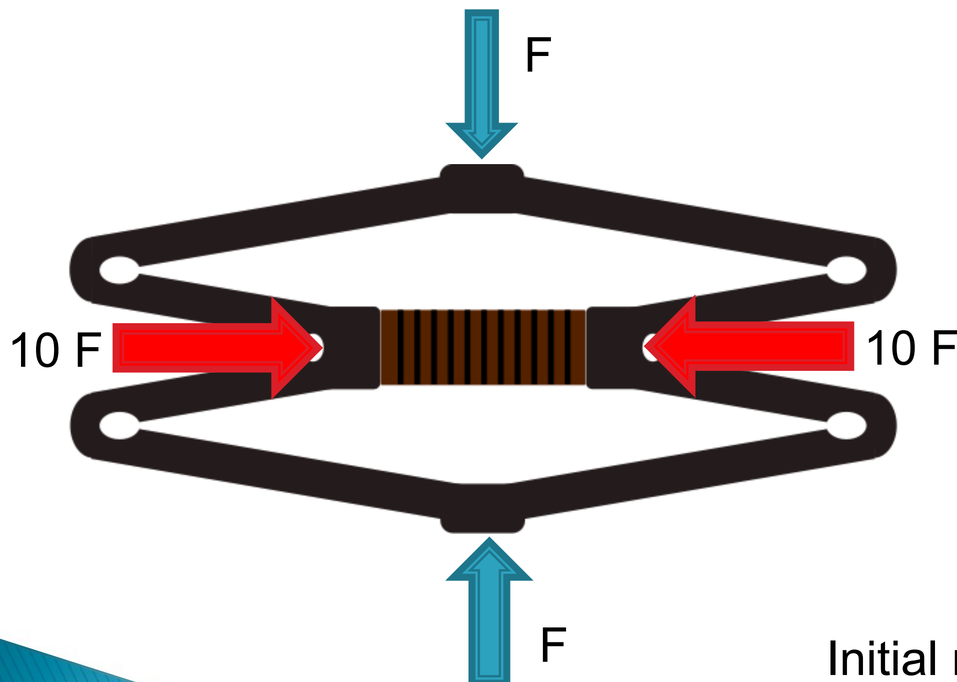
2 mW

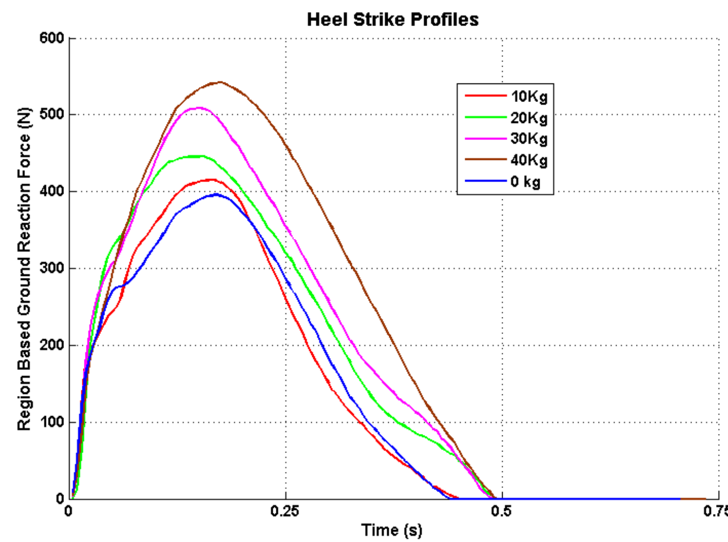


80 mW

Footfall
Piezo Transducer

Use of large multilayer stack, with much higher stored energy than unimorphs or bimorphs; maximise force rather than displacement.





Initial model suggests 10 mJ stored energy per strike = 20 mW continuous power

Conclusions

- A variety of harvesting concepts based on 4 different kinetic energy sources are being explored and optimised
- The greatest potential contribution is from the large load (back-pack) concept
  - Represents the largest potential discomfort
  - Hence the focus on compromise between power & discomfort
- Other sources offer significantly lower power, but with less encumbrance for soldiers not carrying a large load
  - Knee and footfall options focus on greater wearer comfort compared to current solutions, but with sufficient power for the radio demonstrator
  - An integrated radio power source (small proof-mass) offers the least user discomfort, but coupling to gait movement may limit efficiency