Energy Harvesting Using Flexible Piezoelectric Materials

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Presentation Outline

1. Introduction

2. Current energy harvesting research in our research group

3. Prototypes and demonstration

4. Applications and market surveys
Funding

1. EPSRC SPHERE IRC Grant - a Sensor Platform for Healthcare in a Residential Environment  www.irc-sphere.ac.uk

2. Prof. Steve Beeby’s EPSRC Fellowship Grant
Piezoelectric sensing and energy harvesting

- Principle: convert mechanical energy into electrical energy

Sensor

- Signal to Noise Ratio = $v_s / \sigma$

Energy Harvester

- Signal strength and duration
- Energy = $\left| \int_{t_1}^{t_2} V(t) \cdot I(t) dt \right|$
Materials:
(Piezoelectric polymer composite, Ferroelectret)

Piezoelectric polymer composite

PZT-polymer insole

Ferroelectret

PP ferroelectret

PTFE ferroelectret

PDMS ferroelectret foam

LDPE ferroelectret foam
The PZT-polymer film was a screen-printed piezoelectric composite.

Two sizes of PZT particles were used 2 and 0.8\( \mu \text{m} \), mixed with weight ratio of 4:1.

Thermoplastic polymer was dissolved in a solvent producing the binder phase of the composite.

The PZT mixture and binder were blended together with a weight ratio of 2.51:1 with the aid of spatula, speed mixer and triple roll mill.
- A UV-cured interface layer was required to be printed for Polyester-cotton woven fabric substrate to treat the surface roughness.
- A silver-polymer layer was used as bottom and top electrode to extract the charge during d33 measurements.
The $d_{33}$ measurement

- The screen-printed PZT-polymer films showed a $d_{33}$ measurements of 70, 40 and 36 for the devices printed on Polyester-cotton, Kapton and Alumina, respectively.
- This difference in the $d_{33}$ measurements was due to the variations of the clamping effect among the substrates.
- The free-standing (without a substrate) $d_{33}$ value without a substrate was estimated using the following equation

$$d_{33fs} = \frac{d_{33clp}}{1 - 2.\nu_p \left( \frac{v_p}{V_p} - \frac{v_s}{V_s} \right)}$$

- The results showed an average free-standing $d_{33}$ value of the PZT-film of 80 pC/N

![Graph showing $d_{33}$ measurements for different substrates]
How Ferroelectret Generates Energy

Polypropylene (PP) Ferroelectret (Emfit Ltd)

Inflation and charging processes

* $d_{33}$ in the range of 200 to 300 pC/N

A 70µm thick PP ferroelectret can generate 1~2 µJ of energy per 800N of compressive force.
Latest result: more than 100µJ of energy generated per footstep from a 50-layer (total thickness 5mm). And more than 200µJ from a 100-layer.

- This energy is sufficient to power a sensor to transmit data wirelessly!

Model of Ferroelectret for Energy Harvesting Application (capacitor + spring-mass-damper)

\[
V_{\text{out}} = \frac{Fd_{33}}{C}
\]

\[
V_{\text{out}} = \frac{Fd_{33}(h-\Delta h)}{\varepsilon_{33} bl}
\]

\[
V_{\text{out}} = \frac{A}{Y}
\]

\[
t = \frac{F\Delta h \times Y^2}{\left(\frac{1}{R} + C\right) A^2}
\]

Novel Ferroelectret Materials

current multilayer ferroelectret

proposed thick foam ferroelectret

the chemical approach

the physical MEMS approach

blowing process

polymer
mould

plasma bonding

blowing agent
The PDMS ferroelectret foam works the same as other polymer ferroelectrets, but the dimension of its voids is designed and controlled.

Simulation tools are used to optimize the structural dimension for maximum $d_{33}$. 
PDMS Ferroelectret Foam
(Fabrication)

Schematic of fabrication processes

Image of PDMS ferroelectret foam

* $d_{33}$ about 120 pC/N

Measured voltage output under 800N compressive forces with 1 Hz force frequency, 800N and 21MΩ loading resistance
Power Output Demonstration
(Multilayer PP ferroelectret)
Energy Harvesting Insole Application Concept

Personal Self-Monitoring

Energy harvested from insole from footstep

Professional Medical Monitoring

Wireless signal

Microstructure

Self-Powered Monitoring using Energy Harvesting Insole

Multilayer design

* We have developed two energy harvesting insole prototypes for this application
- Using Commercial Zigbee transmitter, for every 2 to 3 footsteps, the transmitter gains sufficient energy from the insole and is able to send 1 byte (8-bit) of wireless data to its receiver, which is 6 to 8 meters away from the source.

- The start-up and transmission of the chipset is solely powered by the ferroelectret insole - completely battery-free!
Using the SPHERE Wearable Transmitter developed in this project, for every single footstep, the transmitter gains sufficient energy from the insole and is able to send 3 to 4 packages of 32-byte wireless data to its receiver.

- A battery is needed to supply the background power (22µW) for this transmitter. The energy harvester extend the battery life for more than 17 times.
Gait data transmitting wirelessly to the receiver on laptop (Prototype No. 2)  
- applications: e.g. indoor localization, identification and sensing
What next?

- We are looking at the applications

1. Insole sensor
2. Wearable identification
3. Indoor tracking

......
Insole sensor currently in use

**Pressure plates**
- Solid (Novel, Zebris, Rsscan, Tekscan, Nitta,..)
  - Flexible (Novel, Tekscan)

**Pressure insoles**
- Novel, Tekscan

**Technologies**
- Resistive
- Capacitive
- Gyroscope
F-Scan @ Southampton Hospital
Objectives

(Current project with medical professionals at Southampton General Hospital)

✓ Market surveys from clinicians, clinical researchers, biomechanics researchers, sports researchers, trainers and general public.

✓ Develop a ‘smart’ insole
Sense Your Sole
Survey

We want to develop new technology to measure foot pressures. At the start of this project, we find it crucial to be informed by stakeholders like you, and target our research right. We therefore thank you for taking part in our survey. The data will be used anonymously in a research grant proposal and are no scientific study as such.

What is your position? (E.g. clinician, physiotherapist, trainer, biomechanist...)
...

What is your main use of plantar pressure measurements?
...

How long have you been using plantar pressure measurement technology?
...

Which system(s) are you currently using?

plate(s): ...

insole(s): ...

What do you like/dislike about your current system?
Positive replies from:

**Biomechanists (n=13)**

- Liverpool John Moores University, UK
- Ghent University, Belgium
- University of Antwerp, Belgium
- Shinshu University, Japan
- Sports University Köln, Germany
- University Hospital Ghent, Belgium
- Amsterdam University, The Netherlands
- Korea National Sport University, Korea
- Thomas More University College, Belgium
- Technical University Chemnitz, Germany
- University of Calgary, Canada
- University of Göteborg, Sweden
- University of Goiás, Brazil

**Clinicians (n=16)**

- Southampton General Hospital

**Footwear companies (n=9)**

- Adidas
- Brooks
- Decathlon
- Fitflop
- New Balance
- Saucony
- Salomon
- Reebok
- Vibram

**Trainers (n=2)**

- Vivobarefoot
- GB Paralympics Swimming Team
Results

Everybody wants good technology (esp. biomechanists)

Cost relatively unimportant (esp. footwear companies)

Userfriendliness and comfort varies
General public view. Third Survey.

- 118 respondents of age groups below:

  - 43%: 16-25
  - 15%: 26-40
  - 9%: 41-60
  - 33%: >61
Use of insoles (25%)

>60% of the percentage who use insoles bought specifically designed to accommodate for their specific needs

- Specifically designed insoles
- In-store general insoles
- Both of the types

- Daily use: 67%
- Sport only use: 23%
- Occasional use: 10%
Problems being solved by use of insoles

- Ankle pain
- Knee pain
- Back pain
- Muscle pain

29%

71%

- Flat feet (35%)
- Splay feet
- Sore feet
- Feet pain
- Arch pain
- Heel pain
In Summary…

- Insoles are being worn by 25% of respondents surveyed;

- Those who benefit from gait analysis and specially designed insoles comprise up to 20%.
Conclusions

1. An energy harvesting insole has been developed. The energy generated from this insole is sufficient to power the wireless transmission of a sensor chipset.

2. Two prototypes are developed to demonstrate the wireless data transmission powered by the energy harvesting insole.

Future Work

1. Further improve the design to improve the energy conversion efficiency

2. Collaborate with institute/industry to develop applications in sensing and energy harvesting, e.g. medical and IoT.
Thank You

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