A review of accelerometry-based wearable motion detectors for physical activity monitoring

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Outline

- **Introduction**
- **Design fundamentals for accelerometry-based wearable motion detectors**
- **Capabilities of wearable systems using accelerometry measurement**
- **Current products overview**
- **Conclusion**

Keywords:
Motion detector, accelerometry, accelerometer, physical activity (PA), energy expenditure (EE), fall detection, gait

Introduction

- ✓ ***Physical activity* (*PA*)**: any bodily movement produced by skeletal muscles which results in energy expenditure

Pathological status

- an independent risk factor for chronic and several common noncommunicable diseases (NCDs)

Energy expenditure (EE)

- a key determinant of energy balance and weight control

***Physical impairment* (*Mobility*)**

- a determinant of motor control, strength, balance, which are factors contributing to fall risk

Ageing process

- is related to functional status and quality of live for older adults

[*World Health Organization (WHO), 2010*]

How to Measure/Evaluate Physical Activity?

- ***Subjective methods***: Diaries, questionnaires, surveys, scales based on observation (e.g., the Berg Balance Scale)
  - ➔ Largely rely on individual observation and subjective interpretation
- ***Objective methods***: by means of a range of sensors and tools using metrological technologies
  - ➔ Sensor-based, or technology-enabled measurement makes long-term, continuous, automatic, and quantitative PA monitoring and evaluation possible, even in a free-living environment
  - ➔ Attempts have been demonstrated based on video recording, optical, acoustical and magnetic measurements using ambient (spatial) sensing techniques

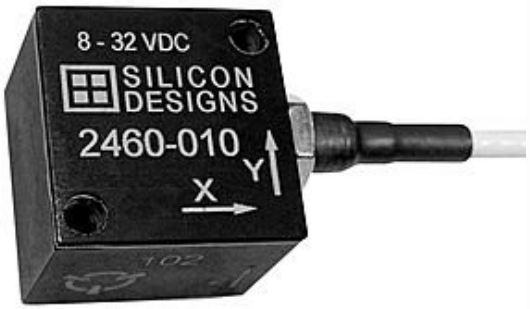
e.g., the VICON System

Why Wearable Sensors ?

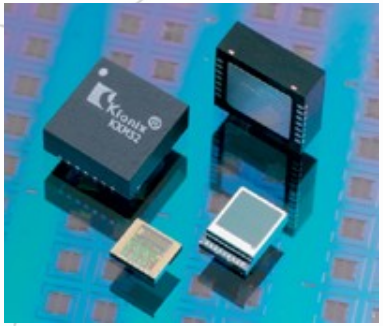
- ✓ The major drawbacks of ambient sensing systems:
  - ➔ Expensive, complex instrument setting, use in limited range and closed environment , privacy issue (video recording)
- ✓ ***Wearable***, or ***body-fix sensors***
  - ➔ Small, easy to wear/carry, unobtrusive
  - ➔ Available technologies greatly advance the performance of wearable systems:
    - Accurate sensors
    - Reduced size and overall layout
    - Enhanced computation capability
    - Wireless telecom.
    - Low power component/circuitry

Why Accelerometry-based Wearable Systems ?

- ✓ ***Accelerometry*: The quantitative determination of acceleration in the entire human body or a part of the body in the performance of a task.
- ✓ ***Accelerometers*** are sensors capable of detecting acceleration and orientation (tilt) of objects in either motion or in static state



•**Bulk housing**
•**High g/impact**

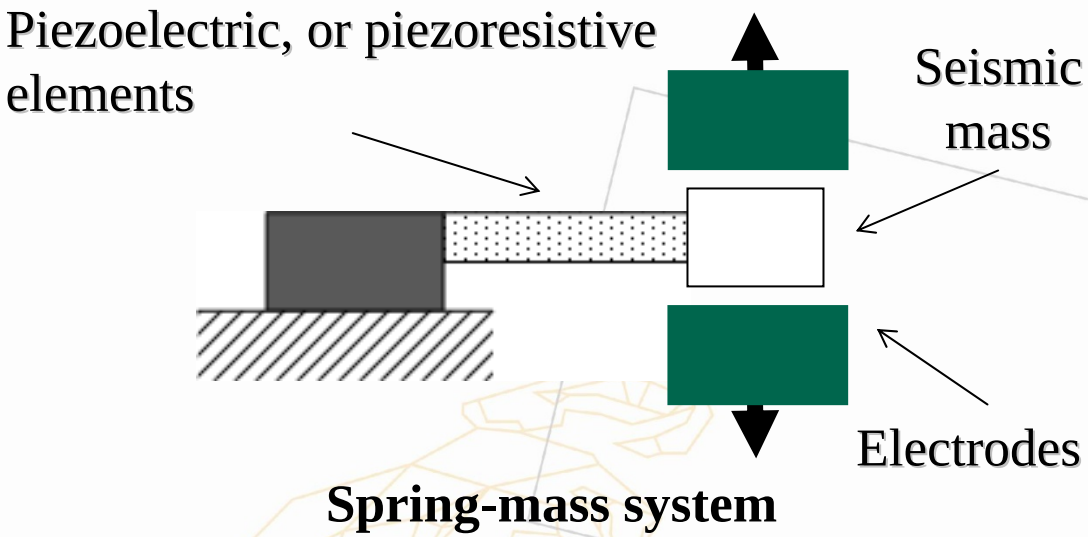


•**Miniature form factor**
•**High precision**
•**Low power consumption**

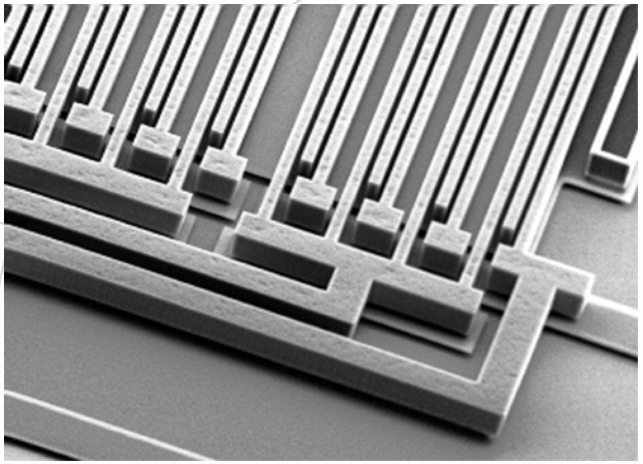
Accelerometric data provides sufficient information of human motion characteristics: acceleration, velocity, position, orientation (tilt), frequency, duration and intensity

Design Fundamentals (1)

- ✓ ***Piezoresistive, piezoelectric, capacitive*** accelerometers



Spring-mass system



Accelerometer manufactured by MEMS technology

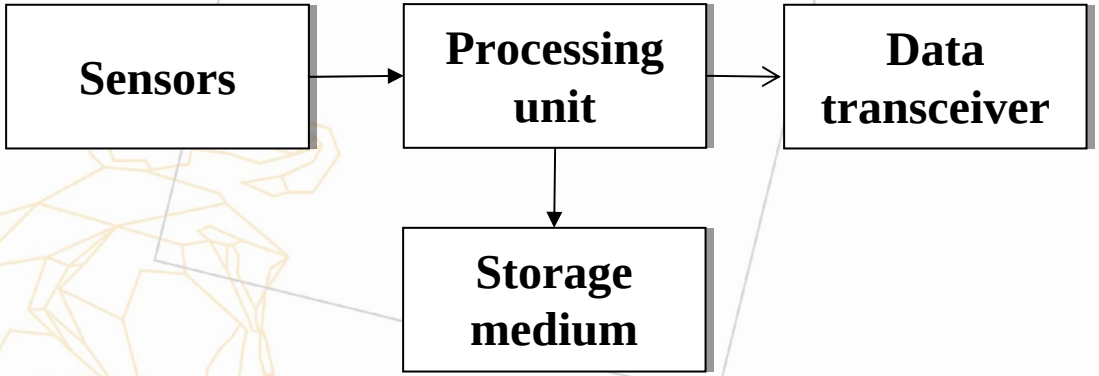
- ✓ Piezoelectric accelerometers do not respond to constant acceleration
- ✓ Capacitive accelerometers having superior performance in low power consumption and high precision, have widely been used in many consumer electronics.

Design Fundamentals (2)

- ✓ Four basic elements constructing a wearable system**:**

Sensors, ***processing unit***, ***storage medium***, and ***data transceiver***

- ✓ ***Data logging***, ***data forwarding***, and ***data processing*** systems
- ✓ ***Offline***, or ***online*** (***real-time***) systems

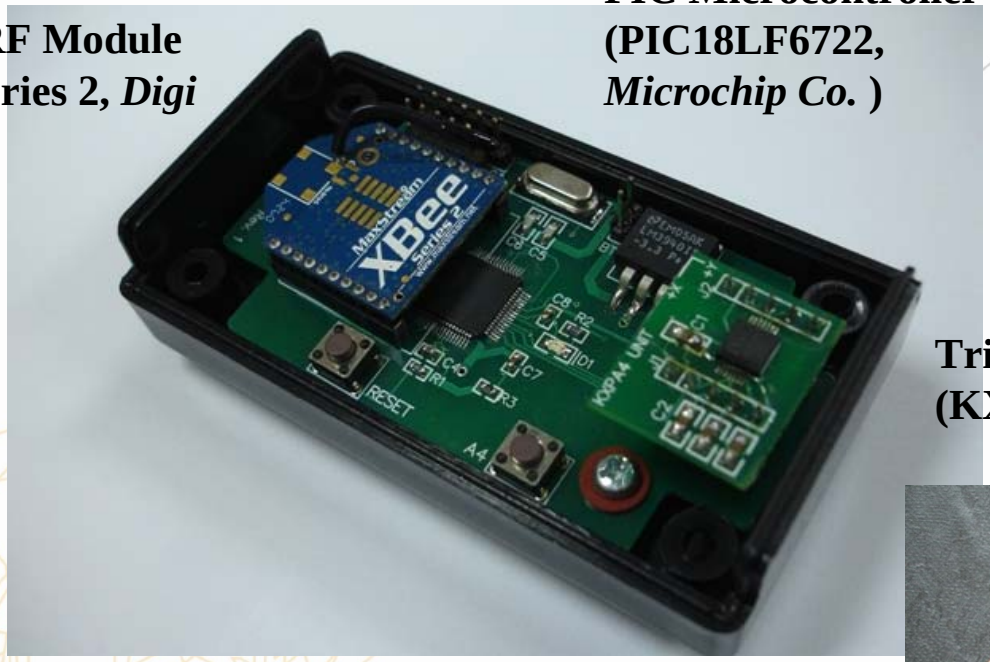


Design Fundamentals (2)

- ✓ Example of a data forwarding system

ZigBee RF Module (XBee Series 2, *Digi Int'l*)

PIC Microcontroller (PIC18LF6722, *Microchip Co.*)



Triaxial Accelerometer (KXPA4, *Kionix*)

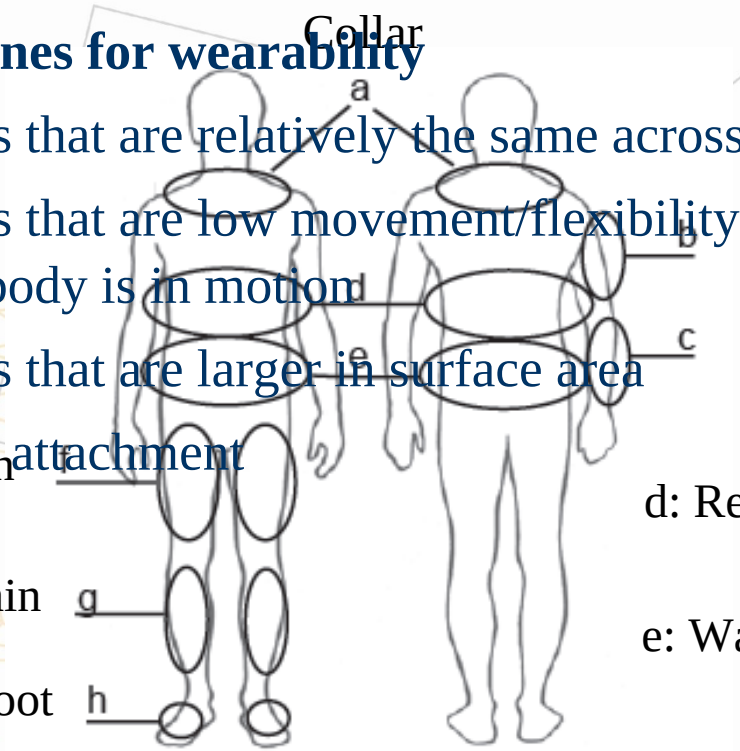
Wearable Activity Detector developed by GRC

Design Fundamentals (3)

✓ **Wearability** — Wearability map generalizes the proper locations of a human body for unobtrusive sensor placement

Guidelines for wearability

- areas that are relatively the same across adults
- areas that are low movement/flexibility even when the body is in motion
- areas that are larger in surface area
- easy attachment



Capabilities of Wearable Activity Monitors (1)

✓ ***Posture and movement classification***

- Static postures: upright, lying
- Dynamic activities: postural transitions (sit-stand, sit-lie), turning, bed movement, walking (level, stairs up/down)
- For the purpose of understanding the behavior pattern of daily activities

✓ ***Fall detection***

- The first trial of fall detector design was published in 1998 [Williams et al., 1998]
- Falls can be identified by utilizing dual-state detection scheme:

(1) Impact, and (2) post-impact lying posture and inactivity

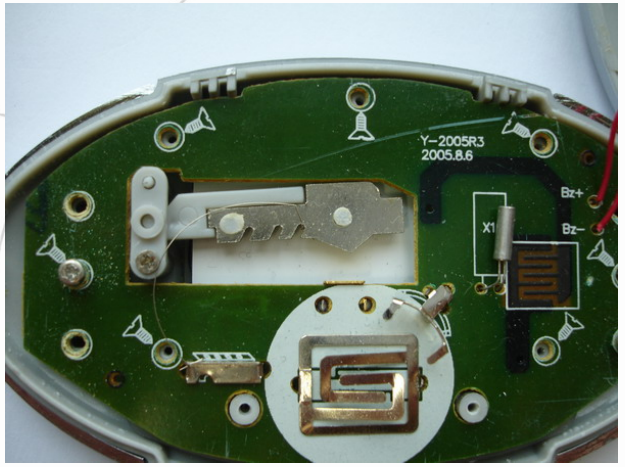
- An essential application for personal emergency response system (PERS)

Capabilities of Wearable Activity Monitors (2)

✓ ***Estimation of energy expenditure***

- Gold standard method: ***Doubly-labeled water*** (***DLW***) method
- Simple measure: Mechanical *pedometer*

  ➔Mechanical pedometers (step counters) cannot reflect intensity of physical activities, a major accuracy problem

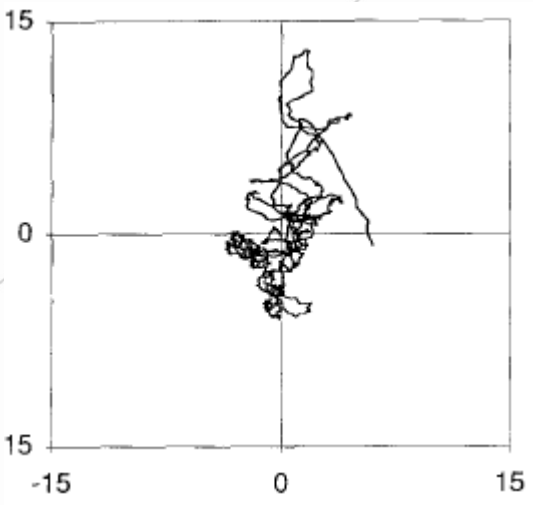


- The integral of acceleration (signal ,magnitude area, SMA) data has been found to be linearly correlated to EE due to activities
- The most common application provided by wearable activity monitors for diet modification, weight control.

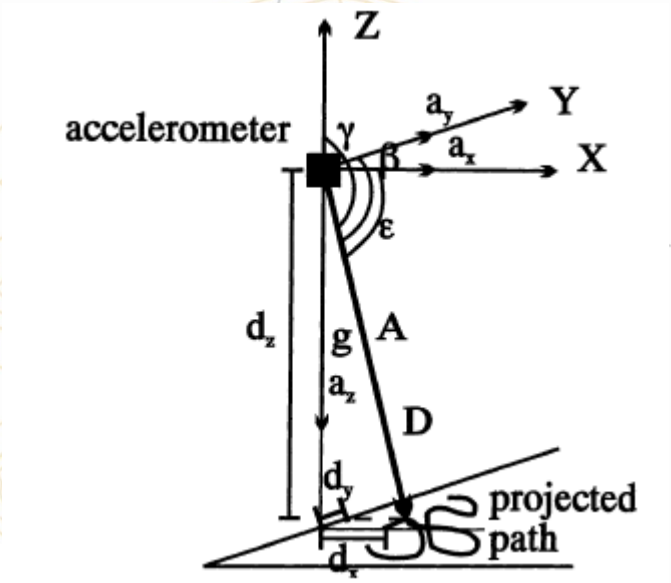
Capabilities of Wearable Activity Monitors (3)

✓ ***Postural stability evaluation***

- Center of pressure (COP) trajectory pattern can be measured by a foot force plate.
- COP trajectory can be calculated from the output of a triaxial accelerometer worn around the trunk [Mayagoitia et al., 2002]

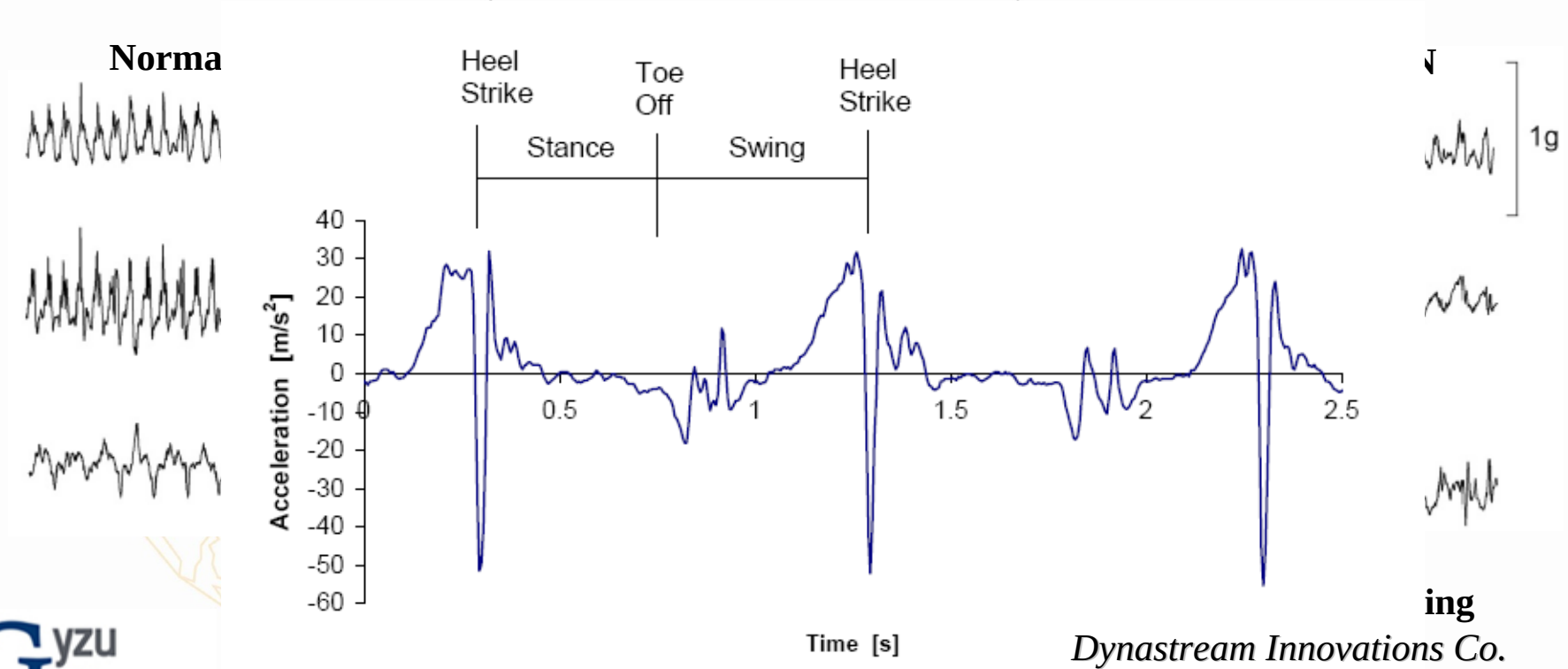


[Collins, et al., 1992]



Capabilities of Wearable Activity Monitors (4)

- ✓ ***Gait pattern analysis***
  - Gait pattern features are indicative of mobility and balance stability➔ fall risk
  - *Spatio-temporal parameters* of gait, such as lower limb velocity, heel strike, heel/toe off can be measured by accelerometry.



Current Products

- Use biaxial or triaxial accelerometers and microprocessors
- Price range from USD199-1599
- Offer similar and comparable function regarding activity monitoring:
    - Calorie burn (EE estimation)
    - Activity/inactivity
    - Step count
    - Travelled distance
    - Sleep duration
- Various activity sensors have been compared in a number of research and study
- Some sensors are exclusively for fall detection, as a PERS application

✓AMP 331 Activity Monitor

- Dynastrem Innovations, a fully owned subsidiary of Garmin (台灣國際航電) has expertise in inertial and wireless sensor/communication devices
- Core technology: SpeedMax Platform

AMP Ware

- Data analysis and management

AMP Link

- Dynastream's Picotan (ANT) RF protocol, 916MHz
- USB 1.1 to PC

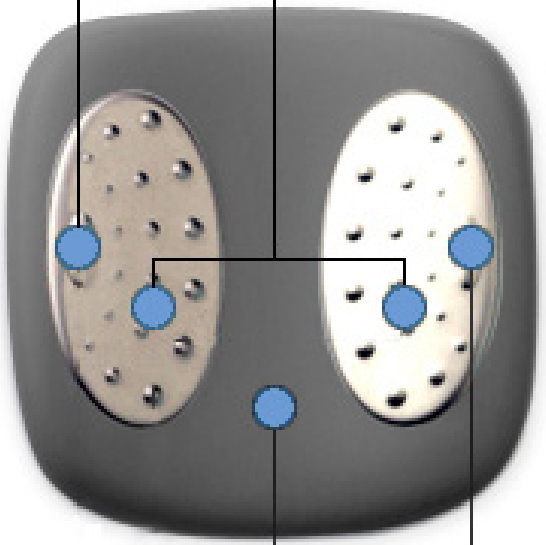
AMP 331

- "Foot Pod" design
- 2-axis accelerometers, DSP unit and wireless

✓ **GoWare Fit Armband** (BodyMedia Inc.)

Skin Temperature
measures the surface temperature of the body

Galvanic Skin Response
measures skin impedance which reflects water content of the skin and the constriction or dilation of the vascular periphery



3-axis Accelerometer
measures motion

Heat Flux
measures the rate at which heat is dissipating from the body

- ✓ **CT1 & RT3** (StayHealthy Inc.)
  - CT1 is a FDA cleared CLASS II medical device f accurate EE estimation
  - RT3 (previously known as Tritrac-R3D) has wide been used in research use

- ✓ **GT3X & GT1M ActiGraph** (ActiGraph)

- ✓ **Fall Detector** (Tunstall)

- ✓ **StepWatch** (OrthoCare Innovations)

- ✓ **iLife Fall Detection Sensor** (AlertOne)

Conclusion

- Sensor-based, objective measurement can provide continuous, automatic, and quantitative assessment of physical activity in long-term monitoring basis.
- Wearable accelerometry-based sensors are low cost, and can offer several capabilities regarding physical activity monitoring, as well as fall detection in a free-living environment.
- Most consumer products are data-logging systems, and the single-device seems the preferred approach
- Calorie calculation is the major application
- There is few product offering complete package of connecting to telecare/telehealth services
- Activity monitoring in conjunction with versatile sensing techniques may widen the scope and applicability in the study of human movement

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Thank you for your listening

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