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

Che-Chang Yang
Doctoral Student, Department of Mechanical Engineering
Gerontechnology Research Center, Yuan Ze University
03/15/2010
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.

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

Piezoelectric, or piezoresistive elements

Seismic mass

Electrodes

Spring-mass system

Accretometer 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

Wearable Activity Detector developed by GRC

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

PIC Microcontroller
(PIC18LF6722, Microchip Co.)

Triaxial Accelerometer
(KXPA4, Kionix )
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

- Collar
- Rear of the upper arm
- Forearm
- Thigh
- Shin
- Top of the foot
- Waist and hips
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)
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]
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.

Example of acceleration pattern measured at head and pelvis during walking

[Dynastream Innovations Co.]
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 Link

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

AMP Ware

- Data analysis and management

AMP 331

- “Foot Pod” design
- 2-axis accelerometers, DSP unit and wireless
✓ GoWare Fit Armband (BodyMedia Inc.)
CT1 & RT3 (StayHealthy Inc.)
- CT1 is a FDA cleared CLASS II medical device for accurate EE estimation
- RT3 (previously known as Tritrac-R3D) has widely been used in research use

GT3X & GT1M ActiGraph (ActiGraph)

StepWatch (OrthoCare Innovations)

Fall Detector (Tunstall)

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.
Thank you for your listening

C. C. Yang (楊哲彰)
s958702@mail.yzu.edu.tw

Gerontechnology Research Centre (GRC)
Dept. of Mechanical Engineering
Yuan Ze University