

# **A Brief Survey of Physical Activity Monitoring Devices<sup>1</sup>**

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## ABSTRACT

*High caloric intake and low physical activities are recognized as key causes behind the dramatic rise in obesity, diabetes and other chronic health conditions over the past few decades. Accurate monitoring of physical activities and energy expenditure is critical to test the effectiveness of current and emerging clinical therapies. This report provides a brief overview of commercially available devices that monitor physical activities. Many of these devices can be effectively used in metabolic assessment, behavior therapy, and weight management, becoming an essential part of the solution to diabetes, obesity and chronic diseases. In this report, we review the following: 1) the function of pedometers and accelerometers, 2) taxonomy based on their mechanisms, measurements, product forms, and data portability. and 3) the role of personal devices integrated with pedometers and complex monitoring devices with multiple sensors in assessing energy expenditure. This report closes with conclusions based on our study..*

**KEY WORDS:** Physical Activity Monitoring, Pedometer, Accelerometer, Sensor

### I. PEDOMETERS AND ACCELEROMETERS

Pedometers are a type of motion sensor that monitors human activity as a person walks or runs. Pedometers are also known as step counters, typically measuring the number of steps an individual takes in a continuous manner. Modern models of pedometers also measure distance walked, activity time, energy expenditure and even calculate human body health indexes based on history information. Nowadays wearing pedometers has become a very popular measurer and motivator of daily exercises. Although pedometers only capture limited types of activities [16] (ie., walking and running.), these devices are widely used in healthcare research and clinical experiments.

In this report, we surveyed both conventional stand-alone pedometer devices and personal digital devices integrated with pedometer functions. We chose seven conventional pedometer models or series (table 1) and four personal devices (table 2) and studied their specifications and performance. Our taxonomy of these devices is based on their mechanisms, product forms, placements, measurement and data storage. We then include a discussion on their performances and limitations.

#### A. MECHANISMS

Modern day pedometers are usually electronic or electromechanical. Based on sensing devices, these pedometers can be divided into five categories:

- (a) *Spring-suspended lever arm with metal-on-metal contact*
- (b) *Magnetic reed proximity switch*
- (c) *Pendulum*
- (d) *Accelerometer*

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Identify applicable sponsor/s (grant number )here.

*(e) GPS*

Type (a), (b) and (c) are considered as electromechanical pedometers. The sensing devices move in response to body's vertical accelerations, opening and closing an internal electrical circuit. The step-counter increases each time when the circuit is open/closed. These electromechanical devices are widely used in Yamax SW [18] and CW [17] series, as well as SportsLine pedometers [15].

Modern accelerometers (type d) are often small micro electro-mechanical systems (MEMS). It consists of a cantilever beam with a piezo-electric crystal (known as a proof mass) and a deflection circuitry [1]. The proof mass deflects from its neutral position when it is forced by acceleration, generating a signal in the circuitry. Single-axis, dual-axis, and triple-axis models exist to measure accelerations in pedometers, depending on the placement of pedometers and the sensitivity requirement. Omron and New LifeStyles pedometers typically use accelerometers. It is also a popular choice in cell phones (such as iPhone [13] and Nokia 5500 Sports phone [8]) that provide pedometer functions because of its smaller size.

Since an accelerometer provides a quantitative measurement of acceleration, it enables the pedometer to not only count steps, but sense the force as a person strides. Therefore these devices usually provide more complex and precise measurement and analysis in terms of energy expenditure.

Recently, people have observed that an advanced Global Positioning Satellite (GPS) receiver (GPSr) with an odometer mode serves as a very accurate pedometer for outdoor activities [12]. While not truly counting steps (no pendulum is involved), an advanced GPSr odometer is capable of measuring distance as accurate as within 1/100th mile to 1/1000th mile depending on the model, while 1/1000th of a mile is approximately the distance of a single pace or 2 steps.

*B. PRODUCT FORMS AND PLACEMENTS*

Pedometers are typically light, portable devices that are worn on a belt. Correct placement is critical for pedometers to take precise measurement. Many require vertical placement on the waist as they detect vertical movement of hips as the user walks and runs. (Yamax CW [17] and SW [18] series, New LifeStyles LifeCorder [5] and NL series [6]). These products usually consist of a clip or a waistband so the device can be attached to the body.

Novel forms of pedometers, have looser requirements on placement. For example, Omron HJ 112 [11] and HJ 720-ITC [10] uses dual axis accelerometers that detect not only vertical but also horizontal movements. They can be put in the pocket or a bag while still taking precise readings. SportLine 955 pedometer watch [15] has dual functions of step counting and time display. It is in the form of a normal watch and is worn on the wrist. Cell phone pedometers, such as the iPhone and Nokia 5500 Sports phone, usually have no specific placement requirements. They can be attached using an armband or simply put in the pocket; however, the precision of their measurement may vary according to its placement [9].

Nike+iPod sport kit [7] is another novel pedometer. It includes a small shoe sensor (accelerometer) and a receiver attached to an iPod. The shoe sensor is a thin patch that is hidden inside the shoe and transmits a signal to iPod.

### C. MEASUREMENT

Pedometers typically count only steps. However, modern models assess a number of other variables and provide more complex functions. The usually seen measurements include:

- (a) *Steps*. Steps are the most basic measurement and used as a basis to calculate more complex data, such as energy expenditure and distance. Some movements other than steps (e.g., bending, jumping, etc.) may cause false readings and thus are called “false steps.” More precise pedometers can effectively eliminate counting false steps. Even “true” steps are handled differently in some pedometers, since different types of walking consumes energy differently. Omron [11] defines the concept of aerobic steps as steps that satisfy two conditions: (1) walk more than 60 steps per minute; (2) walk for more than 10 minutes continuously.
- (b) *Time*. Most modern pedometers provide a timer function to record the activity time. Some products (such as SportLine pedometers) provide a count-down timer mode feature to further motivate exercises.
- (c) *Distance*. Distance is calculated by multiplying number of steps with distance per step. Most pedometers require calibrating distance per step as this parameter varies on users.
- (d) *Energy expenditure*. Some pedometers (such as Omron HJ 112, HJ 720-ITC) estimate calorie consumption during walking by multiplying number of steps with an energy coefficient (Figure 1). This coefficient is determined by the gender and the age of the user. More elaborate design (such as New LifeStyles NL series) use a piezoelectric strain gauge to detect the acceleration of each stride and derive a more precise estimation of energy consumption.

Figure 1. Energy coefficient of walking for people at different ages [11].

	Man	Woman
20's	1.10	1.07
30's	1.05	1.01
40's	1.02	.97
50's	1.01	.95
60's	1.00	.95
70's	.98	.96
80's	.95	.95

- (e) *Complex body health index*. Some pedometers provide extensive software tools that analyze data and conduct more complex health evaluations. For example, SportLine 955 pedometer watch provides a 24 HOUR chronograph at 1/100 second resolution to analyze the user's activities throughout the day. New LifeStyles NL series is capable of calculating Basal Metabolic Rate, which is the amount of energy expended when an individual is at rest. Both

New LifeStyle LifeCorder series and Omron HJ-720 ITC provide PC software tools to manage and evaluate data once the data is extracted from the pedometer.

#### *D. DATA STORAGE*

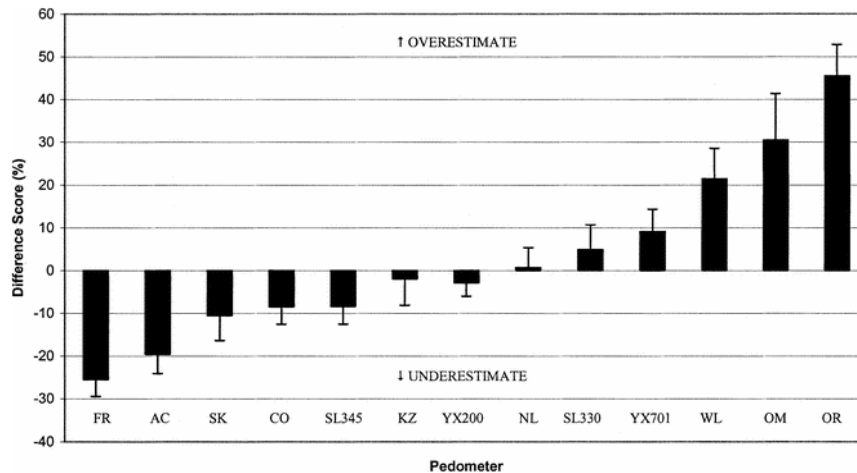
It is important to collect activity data over multiple days or even weeks to enable a more accurate study of the user's behavior. Not all pedometers are capable of storing large data sets or performing statistical analyses on data. In this section, we classify pedometers into three categories based on their data storage capabilities.

- (a) Internal memory only. Many conventional pedometers are stand-alone devices where data can only be stored in their own memory. These pedometers usually provide no interface to port data to the outside and have a limited amount of storage (typically 7-10 days of data).
- (b) Portable data. This class of pedometers (e.g. Omron HJ-720 ITC and New LifeStyles LifeCorder series) usually has a serial port or USB connector that can be connected to a computer. With the additional storage that a computer provides, it is possible to maintain long-term physical activity data and perform extensive statistical analysis using PC software that these devices provide.
- (c) Transient data. In this category, sensor does not have the capability of internal data storage. Data is usually streamed to other devices. An example is Nike+iPod Sport kit. The shoe sensor will send out a signal via a wireless connection each time it detects a step movement. With a wireless receiver, the iPod serves as a data terminal where data is stored and displayed.

#### *E. PERFORMANCE EVALUATION*

A major issue of evaluating pedometers is the accuracy of step counting. Although assessing pedometer accuracy can be conducted by counting steps in controlled laboratory environments, it is not feasible to do so in 24 hours under free living conditions. Research groups at the University of Tennessee [3] [16] benchmarked the performance of 13 models measuring free-living physical activity by selecting a single pedometer (Yamax CW 200) as the comparison criterion, which has consistently been shown as the most accurate devices in controlled laboratory experiments. The result of the experiments shows that there exists a significant discrepancy of precision among these pedometers (Figure 2). Some pedometers overestimate by 45%, while some underestimate by 20%.

Figure 2. Mean difference scores  $[(\text{comparison} - \text{criterion pedometer})/\text{criterion}] \pm \text{SE}$  as a percentage of the criterion estimated steps over a 24-h period [16].



Another issue with pedometers is the accuracy of energy expenditure calculation. Most pedometers estimate energy expenditure by multiplying number of steps with an energy coefficient. However, the limitation of pedometers is that they only record specific types of movements. Depending on the placement of devices, they usually record movement of some specific part of the body. Furthermore, differences in types of physical activities are mostly indistinguishable or unmeasured. Therefore these devices may have limited ability to estimate a user's energy expenditure from a wide range of activities.

## II. MULTI-SENSOR ACTIVITY TRACKING DEVICES

While conventional pedometers and accelerometers have their own limitations, it has become an emerging trend to apply multiple sensing devices to record physical activities. Sensors that are deployed at various parts of body and are dedicated to different physiological measurements in order to provide more comprehensive and convincing knowledge of subjects' physical activities.

### A. SENSEWEAR ARMBAND

SenseWear armband is a multi-sensor device which functions as a core part of the Bodymedia Inc's weight management and body monitoring solutions. Four types of sensors are built in the armband to simultaneously measure physiological metrics including [5]:

- Skin temperature sensor that measures the surface temperature of the body
- 3-axis accelerometer that detects physical movement
- Galvanic skin response sensor that measures skin impedance, which reflects water contents on body surface and the constriction or dilation of vascular periphery
- Heat flux sensor that measure the rate at which heat dissipates from the body

By combining and processing these data on the backend PC, SenseWear can calculate and report energy expenditure and physical activity during and level with clinical accuracy.

### B. BioTrainer Activity Monitor

BioTrainer Activity Monitor [19] is an accelerometer-based device that records physical movements. By employing multi-plane accelerometers, it is capable of detecting both vertical and horizontal movements. The BioTrainer Activity Monitor consists of two parts: (a) BioTrainer Activity Counter and (b) BioTrainer Calorie Burn Counter. The monitor records the duration, intensity, and frequency that physical activity occurs, and correlates body acceleration and body weight to assess energy expenditure.

### **III. Conclusion**

Physical activity monitoring devices are useful tools to evaluate energy expenditure, which has been recognized as a key metric in controlling obesity, diabetes and other health problems [4]. The pedometer is one of the most widely used devices. While conventional pedometers are small and inexpensive, they have a number of limitations including:

- (a) Inaccurate measurement with mechanical sensors
- (b) Limited measurement metrics
- (c) Only sensitive to specific parts of the body movement
- (d) Limited data storage
- (e) Lacks ability to perform statistical analyses















In recent years, a wide variety of new devices have been introduced. These devices implement more advanced sensing technology, have friendlier user-interfaces,, and provide more data storage and processing. We conclude the trend of this evolution of physical activity as follows:

- (a) Mechanical sensors, such as pendulum and spring-suspended lever arm, are replaced with smaller and more accurate MEMS sensors, such as accelerators.
- (b) Devices use multiple plane sensors, such as 2-axis and 3-axis accelerator, instead of single plane sensors to achieve greater precision measuring various movements.
- (c) Devices integrate multiple types of sensors that measure various physiological metrics, such as skin temperature, motion, and heat flux.
- (d) Devices have increased capacity to store and display history data and provide interfaces such as serial port or USB connector to port data to the outside.
- (e) The significance of software has emerged to meet the need for professional data management and comprehensive health analysis.
- (f) Instead of being a stand-alone device, more pedometers are integrated with personal digital devices such as phones, iPods, and watches. These devices have standard software platforms and provide opportunities for an integrated personal healthcare solution that combines various applications.

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Table 1. A Survey of Conventional pedometers

Brand							
Model	 HJ-112	 HJ-720 ITC	 SW Series	 CW Series	 LifeCorder	 NL Series	 955 Pedometer Watch
Measurement	<ol style="list-style-type: none"> <li>Steps</li> <li>Aerobic Steps</li> <li>Activity Time</li> <li>Distance</li> <li>Calories</li> </ol>	<ol style="list-style-type: none"> <li>Steps</li> <li>Aerobic Steps</li> <li>Activity Time</li> <li>Distance</li> <li>Calories</li> </ol>	<ol style="list-style-type: none"> <li>Steps</li> <li>Distance (SW 500/501, 650/651, 700/701)</li> <li>Calories (SW 700/701)</li> </ol>	<ol style="list-style-type: none"> <li>Steps</li> <li>Activity time (CW 300, 600, 700/701)</li> <li>Distance (CW 700/701)</li> <li>Calories (CW 700/701)</li> </ol>	<ol style="list-style-type: none"> <li>Steps</li> <li>Activity time</li> <li>Distance</li> <li>Calories</li> <li>Physical Activity Intensity Level/Graph</li> </ol>	<ol style="list-style-type: none"> <li>Steps</li> <li>Activity time</li> <li>Distance</li> <li>Calories</li> <li>(BMR) Basal metabolic rate</li> </ol>	<ol style="list-style-type: none"> <li>Steps</li> <li>Speed</li> <li>Activity time</li> <li>Distance</li> <li>Calories</li> </ol>
Mechanism	Dual accelerometer sensors	Dual accelerometer sensors	Exclusive Spring Coil and Pendulum	Exclusive Spring Coil and Pendulum	Accelerometer	<ol style="list-style-type: none"> <li>Accelerometer</li> <li>piezoelectric strain gauge</li> </ol>	Pendulum
Placement	Pocket, bag or clip to belt	Pocket, bag or clip to belt	Clip to belt	Clip to belt	Clip to belt	Clip to belt	Wrist (watch)
History	7 days	7 days displayed 42 days in memory	None	7 days daily 2 weeks total	7 days displayed 60 days in memory	7 days	10 days

					(LifeCorder Plus) 200 days in memory (LifeCorder Ex)		
<b>Connection</b>	None	USB	None	None	USB	None	None
<b>Battery Life</b>	6months	6 months	3 years	3 years	2 months (LifeCorder Plus) 6 months (LifeCorder Ex)	10 months	N/A
<b>Comments</b>	Rated 1 <sup>st</sup> place in 10 best pedometers in 2007 by about.com [2]		SW series are considered as highly accurate, and used mostly by researchers		<ol style="list-style-type: none"> <li>1. Expensive. LifeCorder Plus costs 249 each.</li> <li>2. Software provides professional analysis.</li> </ol>		<ol style="list-style-type: none"> <li>1. Provides basic watch function</li> <li>2. Provides 24 hour chronograph at 1/100 second resolution.</li> <li>3. Adjustable sensitivity</li> </ol>

Table 2. A survey of personal devices integrated with pedometers

<b>Brand</b>				
<b>Name / Model</b>	 iPhone + pedometer software	 Nike + iPod Sports Kit	 Nokia 5500 Sports Phone	 Raku-Raku Phone Series
<b>Components</b>	<ol style="list-style-type: none"> <li>1. Built-in accelerometer</li> <li>2. Pedometer 0.2 (software)</li> </ol>	<ol style="list-style-type: none"> <li>1. Nike shoe sensor (accelerometer)</li> <li>2. Wireless receiver</li> </ol>	<ol style="list-style-type: none"> <li>1. Built-in 3D accelerometer</li> <li>2. Nokia sports management software</li> </ol>	<ol style="list-style-type: none"> <li>1. Built-in accelerometer</li> </ol>
<b>Platform</b>	iPhone OS X	iPod OS	Symbian S60v3 9.1	Symbian v6.1
<b>Software License</b>	Freeware	Proprietary	Proprietary	Proprietary
<b>Measurement</b>	<ol style="list-style-type: none"> <li>1. Steps</li> </ol>	<ol style="list-style-type: none"> <li>1. Steps</li> <li>2. Distance</li> <li>3. Time</li> <li>4. Pace</li> <li>5. Calories</li> </ol>	<ol style="list-style-type: none"> <li>1. Steps</li> <li>2. Distance</li> <li>3. Pace</li> <li>4. Calories</li> </ol>	<ol style="list-style-type: none"> <li>1. Steps</li> <li>2. Distance</li> </ol>
<b>Comments</b>	Pedometer 0.2 is an open source software at experimental stage.	Sensor is waterproof and virtually unbreakable		