Wireless Wearable Motion Sensor for Use in Medical Care

Institution:
Department of Engineering, Indiana University - Purdue University Fort Wayne

Student Team Members:
Mr. Scott Hendershot (major: Computer Engineering)
Mr. Adam Hilton (major: Computer Engineering)
Ms. Ma Oo (major: Electrical Engineering)

Advisor:
Dr. Chao Chen (Assistant Professor of Computer Engineering)

Consultants:
Dr. Carlos Pomalaza-Ráez, Professor of Radio Frequency Communications (Department of Engineering)
Dr. Fen-Lei Chang, Director of the Fort Wayne Center for Medical Education (Indiana University)

Introduction and Background

Today's health care systems are burdened by the increasing number of elderly and disabled people needing medical support. New technologies are being used to provide improved support for people bounded in their homes and assisted living environments. Assessing abnormal movements resulting from poor health is essential for monitoring patients' health status and quality of life. The main goal of this project is to design, build, and test a wearable motion sensor system that can be used to record and wirelessly transmit data with information about the motion of a person in need of medical care. The data should carry enough information for the post analysis and possible characterization of movements. The sensor system should be attached to the body in a non-intrusive way and able to operate for long periods of time (possible days) without the need to have the batteries replaced.

Experimental research has shown that normal daily activity can be recorded by attaching accelerometers to the human body and recording the data. Accelerometers measure both static (*e.g.*, gravity) and dynamic (*e.g.*, vibration) acceleration, both including the always-present gravitational acceleration g. If the angle of the sensor with respect to the vertical is known, the gravity component can be removed, and velocity and position can be determined by numerical integration. Movement in three dimensions can be determined using accelerometer measurements over three orthogonal axes. Accelerometers placed at the waist or thigh have been used to resolve resting states, such as sitting, standing and lying, and activities including walking, climbing up and down stairs, and cycling [1][2]. In our project, continuous recordings are wirelessly transmitted and stored on a memory card and then downloaded to a PC for analysis.

Project Description

The main goal of the project is to build a working prototype, which allows for the acquisition and storage of data concerning a person's physical activities. Our system architecture consists of two main components: the *wearable sensor unit* and the *data logger unit,* as shown in Figure 1. The wearable sensor unit is carried by a person, and it measures the person's movements. The measured data are sampled via an analog-to-digital converter (ADC) and fed into a microcontroller. The sampled data are then transmitted wirelessly to a data logger unit, which is fixed at a location close to a grid power source. The measured data will be downloaded to a PC through a cable connection and analyzed using software programs.

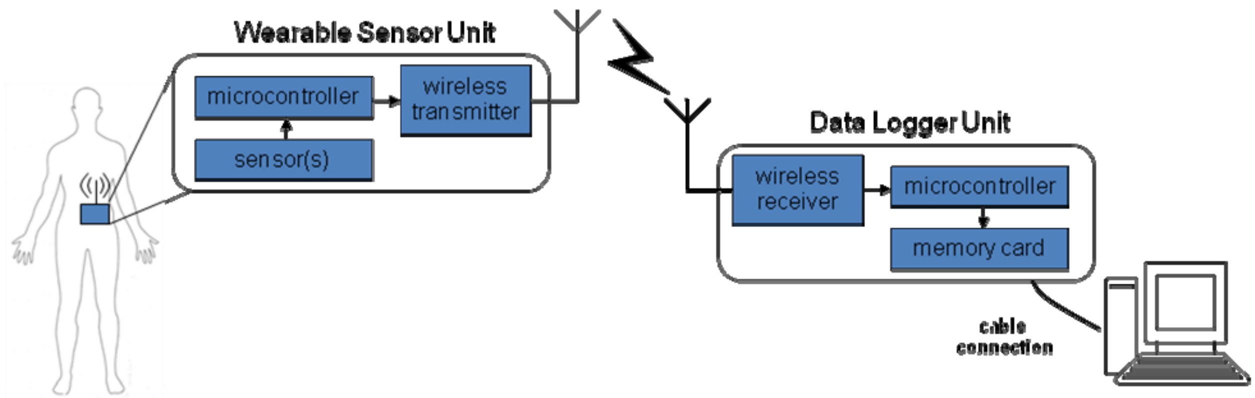

Figure 1. Overview of the wireless wearable motion sensor system for medical care.

Selection of Wireless Standard

The designed product is expected to be used indoor such as in a house, hospital, and nursing home environment, therefore a short-distance wireless communication system is more appropriate for this application. Generally, there are two types of wireless communication standards that are suitable for this project: IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee); both operate in the 2.4GHz unlicensed frequency industrial scientific, and medical (ISM) band.

IEEE standard 802.15.1 is adapted from Bluetooth, which is a telecommunications industry specification for short-range RF-based connectivity for portable devices. Bluetooth is designed for small and low cost devices with low power consumption. Bluetooth has a data transfer rate on the order of 1 Mbps with a complex protocol, since it is geared towards handling voice, images and file transfers. The operational range for Bluetooth is 10 meters. Amplifier antennas can be used to achieve a transmission range of up to 100 meters, but with higher power consumption.

IEEE standard 802.15.4 specifies the physical layer and medium access control for a type of wireless personal area networks which focuses on low-cost, low-speed ubiquitous communication between devices. It is designed for applications with transmission range up to 100 m and data transfer rates of 20-250kbps. 802.15.4 supports a basic master-slave configuration suited to static star networks of many infrequently used devices that talk via small data packets. Compared with Bluetooth, 802.15.4 is more power-efficient because of its small packet size, reduced transceiver duty cycle, reduced complexity, and strict power management mechanisms such as power-down and sleep mode.

After comparing the two choices of applicable wireless standards, it is clear that IEEE 802.15.4 is the better choice for our proposed design which requires short range wireless communication between low-cost, low-power, battery-operated devices for monitoring purposes.

System Implementation

This section explains the details of our design, including the selection of devices and a sample measurement data.

Wearable Sensor Unit

The wearable sensor unit is attached to the waist. We select Freescale MMA7260Q triaxial analog accelerometer as the measurement device, shown in Figure 2. This accelerometer has four different measurement ranges (±1.5*g*, ±2.0*g*, ±4.0*g*, and ±6.0*g*) that can be dynamically set by two input pins. Each range provides different measurement sensitivity. The accelerometer continuously records human movements in terms of accelerations in all three axes. The lower ranges (*e.g.,* ±1.5*g*) are used primarily for accurate measurements of small motions, whereas the higher ranges (*e.g.,* ±6.0*g*) are used primarily for measurements of vibration and impact generated during activities such as running and falling. The MMA7260Q accelerometer has low power consumption with 2.2V~3.6V and 500µA at the normal condition. It can also be set to a low-current inactive mode (*i.e.*, sleep mode) of only 3µA operation current through a SLEEP pin, which further conserves power.

Figure 2. MMA7260Q accelerometer breakout board.

The measured data are fed into a microcontroller and sampled via an ADC. We select the Silicon Labs C8051F353 microcontroller with a built-in 24/16 bit ADC in our design. The microcontroller does simple processing on the data and set the working mode of the accelerometer accordingly. Processed data are fed into an IEEE 802.15.4 wireless transceiver and sent to the data logger unit. For our design, the XBee 802.15.4 radio modem from Digi/MaxStream is chosen as the wireless transceiver, as shown in Figure 3. It can operate under transparent mode with a simple connection with a microcontroller. With a chip antenna, it operates up to 30 meters indoor. The transmission range can be further increased to 90 meters by using a whip antenna. The XBee module has a low maximum transmit power of 1mW and a high receiver sensitivity of -92dBm.

Figure 3. Digi/MaxStream XBee 802.15.4 radio modem with a chip antenna.

Data Logger Unit

The front-end of the data logger unit is a wireless XBee transceiver. Upon receiving the measurement data from the wireless interface, the XBee transceiver forwards the data directly to the microcontroller for processing. We choose C8051F344 from Silicon Labs as the microcontroller in the data logger unit. It has convenient USB interface with a flash memory stick or directly to a PC. The processed data then serve as the basis for the calculations and software development involved in the characterization of movements. The analysis of the sampled data allows possible characterization of human movements such as sitting, standing, rotation, walking, and jumping.

Accelerometer Measurement Test

We test the accelerometer measurement by attaching the wearable sensor unit to a person's waist. The sampled data of acceleration reading is read directly from the C8051F353 microcontroller with the wireless transceiver bypassed. The sampling frequency is 40Hz for each axis.

Figure 4 presents typical accelerations obtained during a 10-s measurement of activities such as sitting, standing, and transitions between sitting and standing. $x(t)$, $y(t)$, and $z(t)$ refer to the frontal, side, and vertical samples, respectively. Because of the Earth's gravity, a positive 1g output is always present in the vertical measurement $z(t)$. It can be seen that different activities show different patterns in the acceleration measurement. Since the movement is mainly in the vertical axis, the acceleration over z-axis depicts the pattern more clearly.

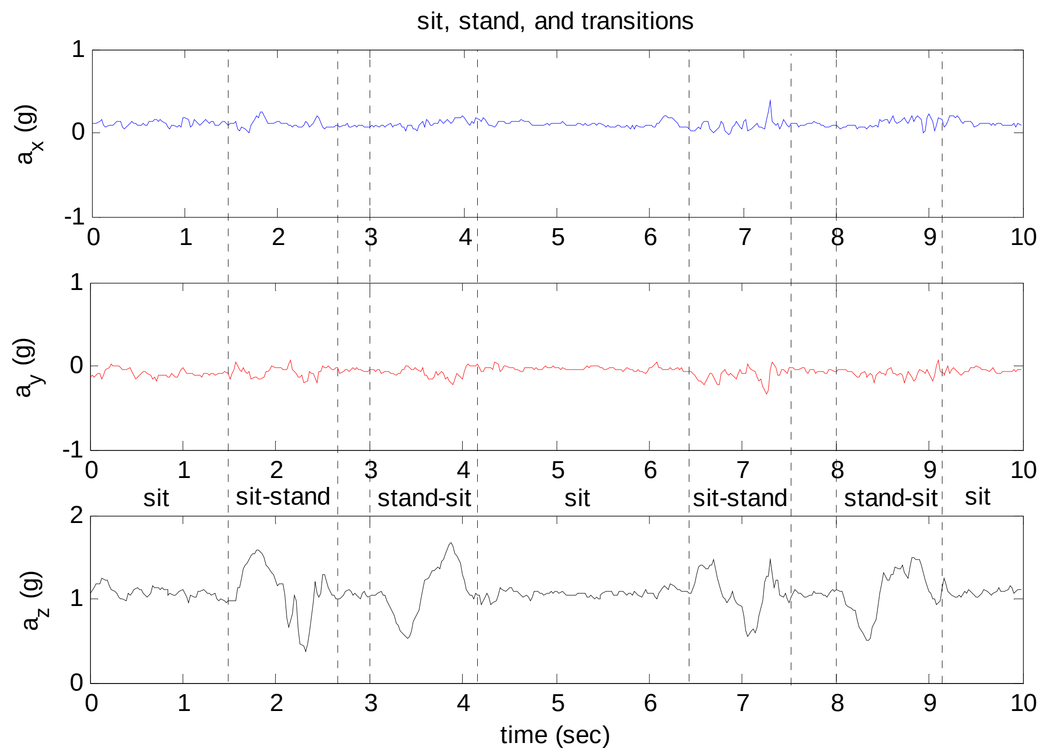

Figure 4. Acceleration measurement over three axes.

Evaluation of ZigBee Transceiver under Interference

Medical monitoring applications require high reliability in data collection. However, IEEE 802.15.4 operates in the 2.4GHz license-free industrial, scientific, and medical (ISM) band, which is shared by several other wireless standards, such as the IEEE 802.11 wireless local area network (WLAN). With the growing popularity of home devices with WLAN interfaces, wireless monitoring system at home using 802.15.4 standard will inevitably face interference from these devices. Moreover, most household microwave ovens operate on a frequency of 2.45GHz. The interference from microwave ovens at home cannot be ignored either.

We have performed a series of experimental tests to evaluate the impact of WLANs and microwave ovens on the performance of 802.15.4 transmission. Specifically, we use an XBee 802.15.4 starter development kit that comes with two XBee RF modules. One module (*i.e.*, the "base" module) is mounted to a USB board that connects to a PC. The other module (*i.e.*, the "remote" module) functions as a repeater by looping data back for retransmission. We used this kit for a point-to-point test, where data are transmitted from the base module, the remote module receives and retransmits data back, and the base module picks the data and compares with the data sent. In each test run, the base module send out 1000 identical data messages, each with 32 characters' length. The timeout value for data reception is set as 100 msec.

Co-existence with 802.11

The overlapping frequency allocations of 802.11 and 802.15.4 are shown in Figure 5. Most WLAN wireless routers operate on one of the non-overlapping channels (*i.e.*, channels 1, 6, or 11) with a 25MHz bandwidth. 802.15.4 devices in the 2.4GHz band have 16 non-overlapping channels to choose from, each with a 5 MHz bandwidth. The output power of 802.15.4 is typically as low as 0dBm, whereas the 802.11 devices usually operate with a much higher power at 15dBm or above.

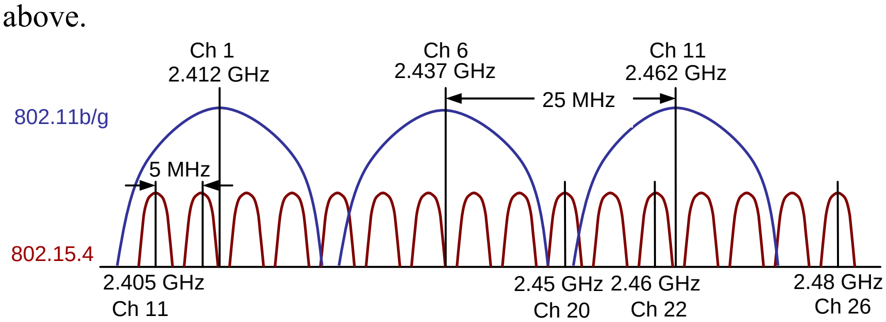

Figure 5. 802.11 and 802.15.4 channels in the 2.4GHz band.

The first set of tests is performed in a one-bedroom apartment scenario on a weekend afternoon. The longest distance between two points in the apartment is about 10 meters, which is within the transmission range of the XBee module. So the two modules should be able to receive each other's data successfully if no interference is present. In this test scenario, neighbors live close in the apartment building. During our measurement tests, eight 802.11g networks are consistently present. Among them, three are with good to very good signal strength (Two are operating on channel 1 and one is on channel 11). The ones with fair but recognizable signals are scattered in channels 1, 6, and 11. Besides these eight networks, a total of nine other different WLAN networks have also appeared during the tests.

We first set our XBee module to work on channel 12 with a center frequency of 2.41GHz. This is a worst case that the offset to the strongest 802.11 channel (*i.e.*, channel 1 in our case) 1 is only 2MHz. We test the data success ratio under different power levels and the results are listed in Table 1. The result for each test case is an average of 10 runs. When the XBee modules are transmitting at a lower power of -10dBm, the average data success ratio is slightly lower and the standard deviation is higher. Next, we let XBee modules operate on channel 20 with a center frequency of 2.45GHz, which is in the middle of 802.11 channel 6 and channel 11. In this case, there is only minor interference from surrounding 802.11 devices: The data success ratio is always 100% even when the XBee modules are transmitting at a low power level of -10dBm.

Table 1. Co-existence test results for 802.11 and 802.15.4 in the apartment scenario.

Power level of Xbee modules	**802.15.4 Channel**	**Data success ratio**	
		mean	**std.**
0 dBm (1 mW)	12	99.36%	0.39%
-10 dBm (100 μW)	12	99.21%	0.75%
-10 dBm (100 μW)	20	100%	0%

The same test was performed in a single-house scenario, where the base module was in the living room and the remote module was in a bedroom in another floor. The distance between the two modules was roughly 6 meters, which is also within the transmission range of the XBee module. During the measurement tests, four different 802.11g neighborhood networks were present. Most of them were using channel 11 including the strongest networks. Therefore, to test the performance of XBee module in the worst case, 802.15.4 channel 22 was selected with a center frequency of 2.46GHz. The data success ratio of the tests in this scenario is shown in Table 2, where the result for each test case is an average of 10 runs.

Table 2. Co-existence test results for 802.11 and 802.15.4 in the single-house scenario.

Power level of Xbee modules	**802.15.4 Channel**	**Data success ratio**	
		mean	**std.**
0 dBm (1 mW)	22	99.89%	0.15%
-10 dBm (100 μW)	22	99.66%	0.23%
-10 dBm (100 μW)	20	99.91%	0.08%

The results show that 802.15.4 devices do experience interference from 802.11 signals. If the user application requires a high reliability, the 802.15.4 devices can select a channel that is further away from the busiest 802.11 channels nearby to avoid the interference. If the 802.15.4 devices can scan the channels to detect the interference and adaptively change their operating channel over time, the performance of the 802.15.4 link would be greatly improved.

Co-existence with Microwave Oven

Since microwave ovens operate on the frequency of 2.45GHz, we set the XBee modules to work on channel 20 with a center frequency of 2.45GHz. To test the worst case, we put the XBee remote module right next to the microwave and set the transmit power to -10dBm. Table 3 shows that when the microwave oven is OFF, there is no data loss (Note that channel 20 also experiences less interference from WLAN). When the microwave oven is ON, the data success ratio is reduced to 96.85% with a high standard deviation of 3.22%. However, if we put the remote module to about 2 meters away, the influence from the microwave oven can be removed.

Table 3. Co-existence test results for microwave oven and 802.15.4 (power level = -10dBm, channel=20).

Microwave status	**Data success ratio**	
	mean	**std.**
OFF	100%	0%
ON	96.85%	3.22%

Summary

In summary, this student project builds a wearable wireless sensor system to acquire data concerning the physical activities of a person in need of medical care. The detailed design involves a triaxial accelerometer and an IEEE 802.15.4 wireless transceiver. This human motion monitor system is inexpensive, energy efficient, and unobtrusive to the human object. Although 802.15.4 devices experience interference from nearby 802.11 networks, such impact can be reduced by selecting an appropriate operating channel. Furthermore, channel 20 should be avoided when 802.15.4 devices are in close proximity to a microwave oven.

References

[1] M. Mathie, B. Celler, N. Lovell, and A. Coster, “Classification of basic daily movements using a triaxial accelerometer,” *Medical and Biological Engineering and Computing*, vol. 42, pp. 679-687, 2004.

[2] D. Karantonis, M. Narayanan, M. Mathie, N. Lovell, and B. Celler, “Implementation of a real-time human movement classifier using a triaxial accelerometer for ambulatory monitoring,” IEEE Transactions on Information Technology in Biomedicine, vol. 10, pp. 156-167, 2006.