Gathering Motion Data Using Featherweight Sensors and TCP/IP over 802.15.4

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On-body sensor wireless sensor networks using standard TCP/IP protocols allows a system to be built that is both convenient and manageable. We describe a set of 10 gram two-axis accelerometers running SIP-based streaming media servers and a lightweight data aggregator. Motion capture data is analyzed for type of motion and stored in annotated form for later analysis for medical applications.

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Abstract

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1. Introduction

On-body sensor networks are used to collect and analyze human behavior and physiology. Wired networks can concentrate power sources and data processing at the core, simplifying the actual sensors at the expense of running wires everywhere. Wireless networks require processing and energy storage at each sensing node, but are much easier to put on and do not restrict mobility.

Traditional wireless on-body sensing networks have used custom data transmission protocols built for the particular application in mind. This (a) prevents the easy re-use of the sensors in other applications and (b) requires some form of networking bridge to connect the sensors with external networks. This paper describes an implementation of an on-body sensing network that uses industry-standard TCP/IP networking protocols over a low-power 802.15.4 wireless network to connect featherweight wireless sensors to data aggregators, and the global internet. The application demonstrated collects motion capture data from accelerometers and creates a time-series analysis of what the person was doing (see figure 1).

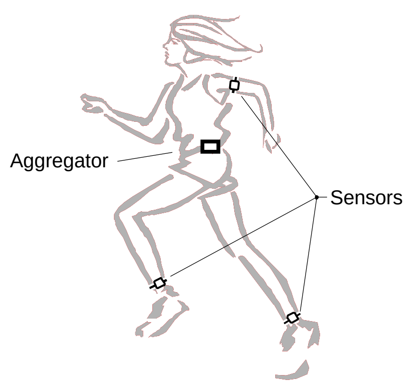

Figure 1. Sample system configuration. Each sensor forwards data to the common aggregator which analyses, annotates, and stores the data. The aggregator uploads data when an external network is available.

2. Hardware & Software Architecture

The sensor network consists of an arbitrary number of featherweight motion sensors, a data aggregator, and access points that connect the low-power wireless network to the global Internet (figure 2.).

Each sensor contains a TI MSP430F1612 microprocessor, an Analog Devices ADXL320 two-axis accelerometer, a Chipcon CC2420 802.15.4 transceiver, and a CR2032 battery. In full operation at a 20Hz sampling rate (including wireless transmission) the sensor burns less than 1 mA giving it an 8-day full-on lifetime. The data aggregator contains a TI MSP430F1612 microprocessor, a 160x120 pixel LCD, a Chipcon CC2420 802.15.4 transceiver, an IrDA interface for direct communication with handheld computers, four buttons, 2 MBits of on-board flash memory, and a lithium-polymer battery. In normal "screen-on" operation with the radio at a 10% duty cycle the unit burns 3 mA, or a lifetime between charges of 10 days.

The sensor and data aggregators run the TinyOS [2] operating system with an implementation of the IEEE 802.15.4 low-power communications protocol. Each device contains a small IPv4 protocol stack with TCP and UDP [3]. The sensors implement a lightweight SIP-based streaming media server over UDP [4]. Each device also runs a local Telnet server and a HTTP server for remote access and control.

An 802.15.4 access point bridges the 802.15.4 wireless network with wired Ethernet. The data aggregator functions as the local 802.15.4 PAN coordinator in the absence of an access point for disconnected operation. In disconnected operation sensor data is collected by the aggregator, analyzed, and a reduced set is stored in the local flash memory.

The utility of using TCP/IP standard protocols becomes apparent when the sensor network is connected via an access point to the global Internet. Any person can point a web browser or Telnet client at any of the sensors or the data aggregator to collect performance data or configure the system. Live data can be displayed graphically by connecting to the SIP-based streaming media servers running on the sensors without disrupting the on-going data collection because each sensor supports multiple simultaneous data streams.

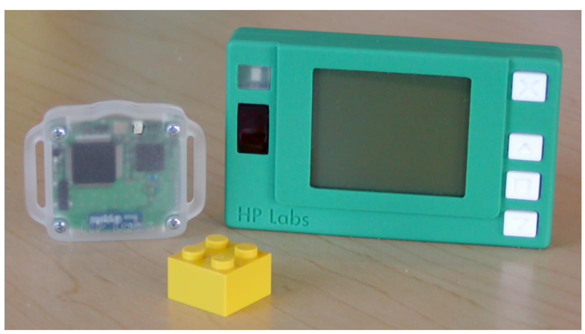

Figure 2. Sensor and Aggregator. The 10 gram sensor measures 9.5x32x41 mm. The 59 gram aggregator measures 13.5x46x77 mm. The access point is not shown.

3. Motion Capture Data

Data was captured during a series of activities using the device in an ankle mounted position with the x-axis accelerometer perpendicular to the ground and the y-axis accelerometer facing forward. Sitting, Standing, Walking and Jogging activities were performed at planned times. Figure 3 shows the data collected during the experiment. The 20Hz raw data from each accelerometer is shown in the upper figure and processed data created by convolving the RMS data for the x and y axes as calculated by:

$$RMS_{xy}(n) = \sqrt{x(n)^2 + y(n)^2}$$

with a 100 sample boxcar filter:

$$x(n) = \begin{cases} 1 & 0 \le n \le 100 \\ 0 & otherwise \end{cases}$$

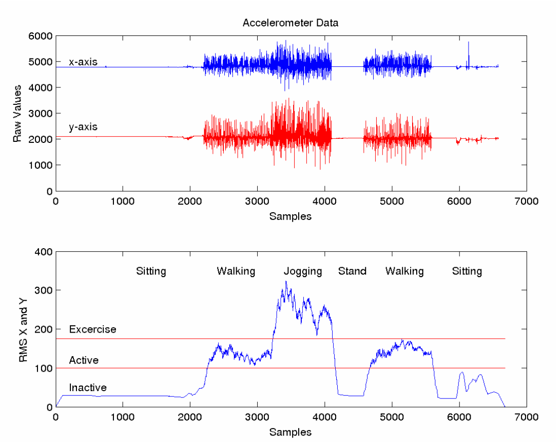

Figure 3. Data collected from the system. Top figure shows the raw data collected from the two-axis accelerometer and the bottom figure shows the low pass RMS values with possible thresholds.

as shown in the lower graph. Two thresholds are shown which would differentiate periods of inactivity from periods of activity and exercise. Applying this method to an entire day's readings would generate a daily % activity measure which could be used for home monitoring of depression, CHF and exercise compliance.

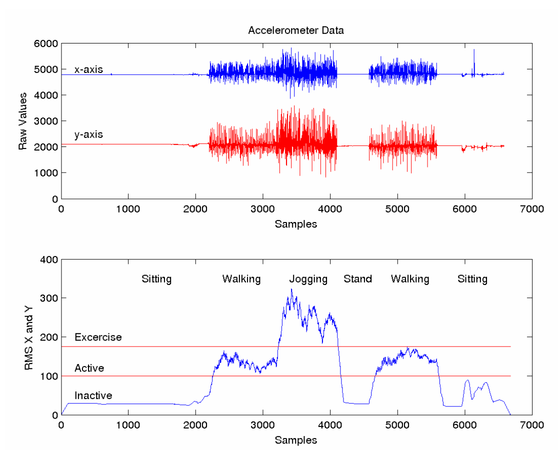

Figure 3. Data collected from the system. Top figure shows the raw data collected from the two-axis accelerometer and the bottom figure shows the low pass RMS values with possible thresholds.

4. Conclusion

This small lightweight two-axis accelerometer provides a pragmatic approach to on-body activity sensing. TCP/IP protocols simplify implementation and debugging of streaming data, allow testing to be done off-body as well as on. The light weight and the ability to sense without requiring skin contact make the sensor easy to wear as a stand alone device, but also allow the device to be easily integrated into clothing or shoes. The low power requirements allow the sensor to be work for many days without requiring recharging. Further information on medical applications, hardware, and software for the featherweight devices is available from [1].

5. References

[1] Christian, et al, "Fingertips of the Network: Featherweight Communicators and Sensors", HPL-2005-114, June 2005.

[2] TinyOS open-source operating system for wireless embedded sensor networks; http://www.tinyos.net.

[3] The uIP Embedded TCP/IP Stack, http://www.sics.se/~adam/uip/

[4] Session Initiation Protocol, Internet RFC 2543, March 1999.