Development of a Research-oriented Wireless System for Human Performance Monitoring

by

Jonathan Hill
ECE Dept., Univ. of Hartford
jmhill@hartford.edu

Majdi Atallah
ECE Dept., Univ. of Hartford
atallah@hartford.edu

Kevin Ball
Physical Therapy Dept., Univ. of Hartford
keball@hartford.edu

Abstract

Our goal is a flexible platform for human performance research that is configurable for a number of sensor types, provides various options for information processing, and is useful in various simple protocols. A first demonstration involves the use of a pair of six-degree of freedom sensors to monitor angular and translational physical motion in a research participant. The sensor units are attached to a joint or targeted region on a research participant. A sensor monitor is connected to a hip belt-mounted device. The system is not tethered so that no wires run between the participant and rack-mounted instrumentation. The system provides flash memory for logging and provides short range wireless communications for the laboratory setting to allow for real-time data analysis, as well as to provide a remote user interface to the monitor device.

The most notable feature of the dynamic monitoring system is the inclusion of an embedded microprocessor allowing real-time evaluation of motion, and, therefore, the provision of feedback to the research participant and/or clinician. The ability to provide such bio-feedback during the daily living activities is desired by clinicians. Such capability goes far beyond the guidance that can be provided within the setting of a clinic.

The availability of low-cost field programmable gate arrays (FPGAs) and wireless technologies provides new opportunities for the development of a wearable computing platform for human performance research. Such FPGA-based systems are most appropriate in low volume applications that call for the utmost in flexibility. Given the initial research-oriented nature, our use of an FPGA is appealing. This dynamic monitoring device will enable further investigations of the feasibility of use in clinical research and practice settings.

I. Introduction

We are developing a research-oriented system useful for human performance studies. The aim is to provide detailed monitoring and analysis of human joint and body motion that is suitable for brief, moderate, and even extended periods of time. There are numerous examples of treatment protocols in which a clinician asks the patient to maintain a specific posture, avoid lax movements, or to create (or not create) joint movements in a particular direction. In the clinic, it is only possible to monitor or examine the patient for a brief period of time. Furthermore, such monitoring is often done visually, typically requiring the therapist to spend time in a manner that is somewhat unproductive in the clinic. The development and effective application of the dynamic monitoring device has the potential to enhance patient treatment efficacy and documentation because it brings increased opportunities for maintaining efficiency and cost control in the management of a dynamic clinical practice.

Figure 1 is an overview of the overall system as used with the six-degree of freedom sensors. Each sensor is placed at a targeted region or joint of the research participant. The sensors connect to a hip-mounted device called the monitor. A simple wireless link [1] provides short-range connectivity, useful in a clinical setting for real-time data analysis, as well as providing a remote user interface to the monitor. Here, the term “wireless” means that the monitor system is not tethered to any external device. The wireless communications hardware has been tested using the simple wxlib software library described by Hill [1]. A compact flash memory card provides independent long-term data logging.

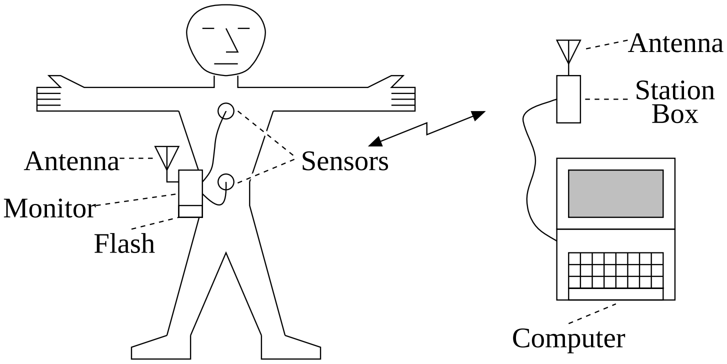

Figure 1: Overall System

Collectively, the monitor, sensors, compact flash card, and antenna are referred to as the monitor system. The station box is the companion device required for wireless communication. In addition to wireless and to allow for convenient off-line data analysis following data collection, the compact flash is directly readable by a computer. This use of compact flash allows for data to be remotely collected over an extended period of time.

The availability of low-cost field programmable gate arrays (FPGAs) and wireless technologies provides new opportunities for research in human performance studies involving the use of wearable or otherwise embedded microprocessor systems. Such a system provides several opportunities to be flexible. In being microprocessor based, the system is programmed with software and provides decision making capability. The use of standards-based communications will eventually allow for the design and use of various sensor types in a wired sensor network. Finally, the choice to use an FPGA affords the system designer the flexibility to modify processor hardware without actually changing components in the system.

II. Sensor Units

Each sensor provides some intelligence in processing a desired signal. By reducing signals to digital form, a more robust signaling scheme can be used and there is less opportunity for interference from and to other electronic devices. Figure 2 is such a sensor [2], mounted along with cabling. The sensor is a complete six-degrees of freedom inertial measurement unit. It accurately measures angular rates up to +/–300 degrees per second and accelerations up to +/–10g. The maximum sample rate is 64 samples per second. The unit is appropriate for use in clinical research but may not be suitable for certain high-speed sports activities. The unit produces angular incremental and velocity incremental data in conventional asynchronous serial frames. Despite drawing only one-half watt of power, the unit contains three microprocessors used to make it truly a stand-alone unit. Modular cabling is used with RS/EIA-422-like signals.

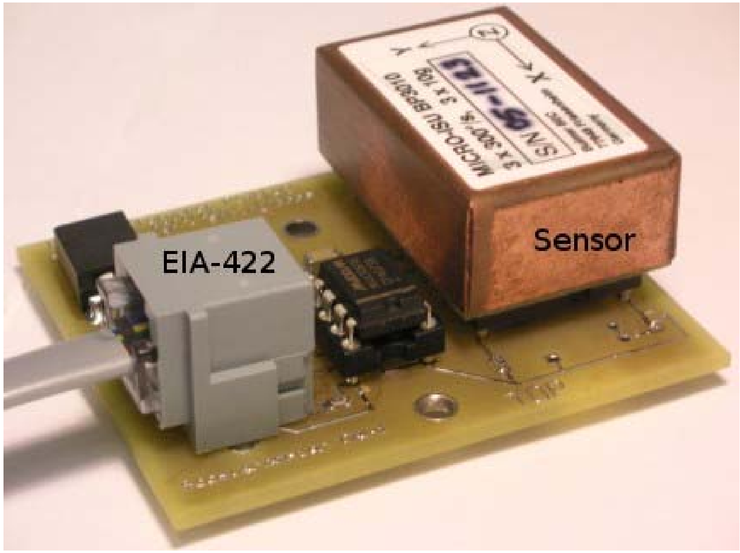

Figure 2: Mounted Sensor with Cabling

In selecting the cabling, we first consider that the sensors are to be mounted upon various regions of the body and can be expected to undergo vigorous motion at times. We chose the modular cabling in Figure 2 because it is relatively light and flexible. In using this cabling on a research participant, we selected a low-voltage signaling standard. Figure 3 is the RS/EIA-422-like signaling scheme we chose to communicate between the present sensor and the monitor. The standard uses low-voltage differential signaling which provides a level of noise immunity along with higher speed communications. In being electrically balanced, this format is less likely to interfere with other electronic devices.

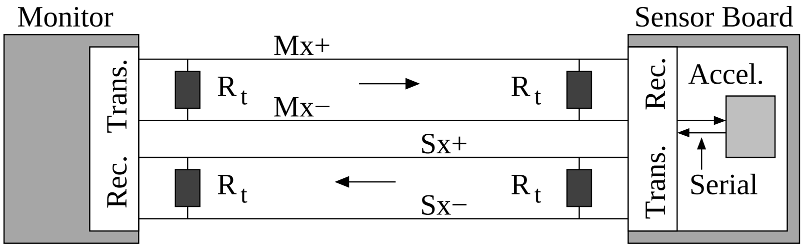

Figure 3: Communications between a Sensor and Monitor

This standard is flexible, allowing for other sensor types. In Figure 3, resistors are used to terminate each wire pair. The standard allows each wire pair to have one driver and multiple receivers so that future sensors can communicate with the monitor using a request/respond protocol-based network. Inside the sensor board, the accelerometer communicates with a conventional UART format, which is converted to and from differential form. Given the arrangement, only point-to-point links are possible with the current sensor. We use six-conductor cabling, which includes the four wires in Figure 3, along with power and ground.

III. Monitor System

Figure 4 is the prototype monitor. The lower board is an off-the-shelf development board, which includes a Spartan-3 series field programmable gate array (FPGA), which is the black square to right. The white cable near the center (JTAG) of the figure is used to configure the FPGA and onboard platform flash device. The upper board is our custom adapter card. A compact memory device is to the left, and the transceiver hybrid and RF connector for the antenna are near the center of the adapter. The EIA-422 chips and modular connectors are to the right. Once configured, the monitor system can be made more compact by folding so the adapter card is above or below the development board.

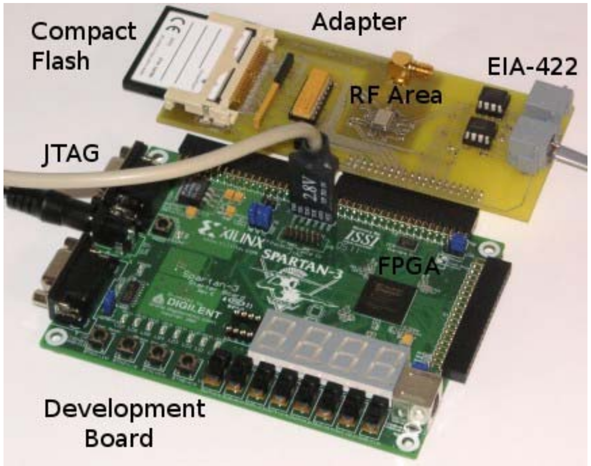

Figure 4: Prototype Monitor System

The block diagram in Figure 5 makes it obvious that the monitor system is actually an embedded microprocessor system. Such a processor is needed to provide all the required behavior, which includes communicating with sensors, performing data logging, wireless communications, as well as providing independent decision making capability. Much of the system is in the FPGA, which is an array of configurable logic blocks, along with a configurable interconnecting resource that is also called the FPGA fabric. Such FPGA-based systems are appropriate in low-volume applications that call for the utmost in flexibility. Given the initial research-oriented nature and modest performance requirement, our use of this FPGA is appealing.

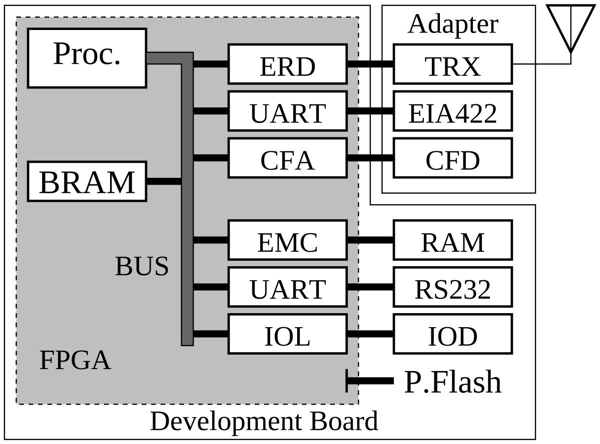

Figure 5: Monitor System Overview

Code written with a hardware description language, such as VHDL, is used to produce an image file or bit file, stored in the platform flash (P.Flash), which configures all aspects of the FPGA, including the on-chip block RAM (BRAM) memory. Note that the image file here is not executable but rather can be thought of as being the system itself. Once the FPGA is configured, the system executes machine code just like any microprocessor. As such, the software is written in C, using conventional software development tools.

With the modest performance requirements, we chose to use a fairly generic 32-bit RISC-type softcore microprocessor [5], which means that rather than being an embedded core, the processor is implemented in the fabric along with the rest of the system. The external memory controller (EMC) provides access to 1 Mbyte of RAM. A UART provides RS232 communications, which is useful in development. Input-output logic (IOL) connects simple devices such as switches, push-buttons, and LEDs and the seven segment displays.

The transceiver (TRX) is an off-the-shelf hybrid [6] operating in the 900 Mhz band. The device is unique in its fast transition between transmit and receive modes and is operated in half-duplex. While the device can signal as fast as 1 Mbps, we arbitrarily selected 250 kbps. A pair of UARTs connect to the cabling, and additional logic (CFA) connects a compact flash card (CFD).

IV. Present Status and Summary

We are developing a research-oriented system useful in human performance studies. In developing the system as an embedded processor, we are producing a system that is both flexible and dynamic. As of this writing, the system is still in development. MATLAB scripts executed on a personal computer are currently used to examine the sensor output data stream. Future processing will be performed entirely in the monitor system. When completed, this device will help maintain efficiency and cost control in the management of a dynamic clinical practice by enhancing patient treatment.

References

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Biography

JONATHAN HILL is an assistant professor in Electrical and Computer Engineering at the University of Hartford in Connecticut. He instructs graduate and undergraduate computer engineering computer courses, directs graduate research, and performs research involving embedded microprocessor based systems. His specific projects involve digital communications, signal processing, and intelligent instrumentation.

MAJDI ATALLAH is a graduate student in Electrical and Computer Engineering at the University of Hartford in Connecticut. He received a bachelor's degree in Computer Engineering from the University of Hartford. His interests involve embedded microprocessor based systems, VLSI, and computer data networks.

KEVIN BALL is an assistant professor in the Department of Physical Therapy at the University of Hartford in Connecticut. He instructs doctoral level courses in biomechanics, kinesiology, and research design. Kevin has more than 15 years of experience conducting and directing research on the 3D biomechanics of human motion. He is the founding director of the Human Performance Research laboratory at the University of Hartford.