Interdisciplinary Development of a Biokinematic Data Acquisition System

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I. Project Description

The Quest real-time operating system [1,2] by Professor West's research team seeks to enable safe, secure, predictable and efficient task execution on emerging embedded and multicore platforms. While Arduino devices have proven popular for rapidly prototyping embedded computing applications, more recent single board computers (SBCs) such as the Raspberry Pi, Beaglebone Black, Galileo, Edison, and Minnowboard offer greater processing capabilities. The Edison, for example, features a dual core Atom processor, with a separate Quark MCU for additional real-time processing. Unlike simpler Arduino devices that operate without an operating system, many of the more powerful SBCs run a version of embedded Linux (e.g., Angstrom, Raspbian, or Yocto/Poky) that lacks the necessary timing and efficiency required for many sensor-based, real-time applications. One such challenge area is the acquisition of biokinematic data from an on-body sensor/processing unit in real-time. The new collaboration between Richard West (CS, CAS), Sheryl Grace (ME, ENG) and Cara Lewis (PT/AT, SAR) proposed here, applies the Quest operating system to a biokinematic data acquisition and visualization system to explore the enabling features of the operating system.

For this research, we have selected a single example that well represents the challenges and limitations for real-time, local, biokinematic sensing. In particular, we will focus on the development of a suite of sensors that would be worn by a person learning to skate for ice hockey. A successful system will obtain data regarding body positioning while skating and provide it in a useful, graphical form, to provide feedback on stride production to the skater, her parent, or her coach. The graphical output becomes analogous to the mirror used by students studying dance.

Successful completion of the project will open many avenues for further research. For instance, Co-PI Lewis currently utilizes 3D video based position acquisition systems in her lab to study human movement and its connection to hip pain. If an accurate, robust, in situ measurement device for tracking gait existed, research on environmental effects on gait production could be studied. In addition, one could study whether user feedback to patients working to change their gait increases the success rate or amount of time needed to produce the change. In the mechanical engineering area of biomechanics which traditionally relies on animal testing to determine the effect of applied loads on bone growth, researchers would be able to study repetitive loading of bones during adolescents that is hypothesized to lead to adult joint issues. More efficient microprocessing capabilities will open new possibilities in traditional controls applications, including communication between and control of small autonomous boat swarms for acoustic monitoring in the ocean. So far, the Quest operating system has been designed to work on the x86 processor family. The success of this project would motivate future development of similar operating systems for other microprocessing systems, including those based on the ARM processor.

I.1 Research Questions

Three research questions from three disciplines will be addressed through this research. First, it is essential to determine which position metrics would best capture the required elements of a good skating stride. Co-PI Lewis will use her clinical and research expertise in analyzing human movement as a basis for determining the best suite of body locations and motion metrics for analyzing skating stride. As a clinical training physical therapist, Co-PI Lewis is an expert in assessing how someone moves and detecting differences from “ideal” motion. As a researcher, she is able to determine what metrics will best capture the difference between an individual’s motion and the ideal. This unique combination of skills can be seen in her publications that include both the clinically observed motion and the 3D motion analysis measures of the motion [3-6]. Previous studies [7,8] regarding the kinematics of hockey strides provide necessary background information. These past studies will be supplemented by discussions and visits with skating coaches from Boston area hockey development programs.

Second, a method for acquiring the position metrics must be devised. At a minimum, an Inertial Measurement Unit (IMU) with 9 degrees of freedom: 3 accelerometer, 3 gyro, and 3 magnetometer will be utilized. It may be important, though, to incorporate the more extensive IMU/GPS system as this will allow extension to other applications with localization and navigation requirements. Both IMU and IMU/GPS systems will be investigated. Normal filtering methods used to integrate IMU data to obtain position information require an accurate dynamical model of the motion. Such a model is not available for the motions associated with general human movement. A more general filtering process based on work by Mahoney [9] and implemented by Madgwick [10] has been used recently to integrate IMU data acquired from a device attached to someone’s shoe [11]. The results provide motivation for this project. Co-PI Grace will take the lead on researching whether there is a way to create a dynamical model that represents the skating motion and whether the Mahoney algorithm can be used with a real-time data acquisition system. Based on her findings, estimates of the accuracy of the positions that can be computed from the system will be made. This will lead to subsequent decisions regarding the ability to obtain the desired position metrics or the need for alternate metrics.

Third, an optimal method for collecting and analyzing the data as well as communicating it, storing it, and visualizing it must be developed. Co-PI West together with a graduate student (and supported by Grace and Lewis) will address these issues. A method to optimize the amount of processing that happens on-board the microprocessor versus on the receiving device will be developed. At this time, it is envisioned that multiple sensors will be communicating with a single receiving device. However, depending on the available on-board microprocessor computing power and its connectivity capabilities (e.g., number of GPIOs, I2C, SPI, USB, Bluetooth, Ethernet, WiFi, ZigBee and CAN bus interfaces), we may consider the intercommunication between multiple devices. Depending on the number of sensors required for the application, it may be impossible to aggregate them on a single device, or at least will require the real-time, parallel processing of multiple data inputs. In either case, the receiving device will most likely be used to visualize the results in a useful way for feedback to the skater or trainer. Extensions to the PI’s Quest-V system [12], to combine real-time processing with distributed, mixed-criticality computing (e.g., involving legacy, less time-critical Linux services) will be considered.

II Budget ($42,367) and timeline (one calendar year)

A graduate student from the Computer Science Department will be funded for one year ($34,067). In Spring 2016, the graduate student under the supervision of Professors West and Grace will acquire the required hardware, implement the Quest operating system on the target platform, test the IMU and IMU/GPS, implement a Attitude and Heading Reference System (AHRS), and begin to test various integration filters. Professor West is already working with Intel to develop Quest for the compact Edison platform. While we hope to develop an inexpensive body tracking device, it will be important to compare the capabilities of both IMU and integrated IMU/GPS approaches. Professor Lewis will develop the required metrics to define a good skating stride. During the summer, the communication method will be developed and tested by the student. Analysis and optimization of the acquisition, computation, and communication load distribution will lead to a tailored approach for all three facets based on the Quest operating system. In the fall, the student will begin full testing of the system and develop a user interface. A full validation will be completed by acquiring on-body data from the new system simultaneously with the acquisition of body position data from the 3D motion capture methods utilized in Professor Lewis' lab.

The hardware list includes the required components to create four measurement systems. A single system will require: 1 Edison microprocessor ($75), 1 IMU ($75), 1 battery pack ($25), communication options ($100), basic wires and connectors ($50). Total: $325(1 system), $1300 (4 systems). The higher accuracy IMU/GPS system ($5000) and a single receiving laptop will be required ($1500). The validation studies to be done in Professor Lewis' lab will require the assistance of one of her undergraduate researchers ($500).

III Summary and highlights

- An interdisciplinary project connecting three faculty from three colleges at BU is proposed.
- A specific system to track the body position of ice hockey skaters during stride production will be developed. The features of a new operating system will be exploited. Such a system will demonstrate the ability to acquire accurate biokinematic data from an on-body system.
- Several areas of future research will benefit from this catalyst project including : physical therapy research investigating in lab versus in community scenarios; mechanical engineering research focussed on the control of multi-unit systems such as unmanned air vehicles; and computer science research focusing on optimization of scheduling and timing as well as the development of operating systems for other microprocessing platforms.
- Previous investigations by Professors West and Grace on position data acquisition from IMU/microprocessors and the existence of the Quest operating system mean the start-up time for the project will be minimal.
- At the end of one calendar year, a working, on-body, biokinematic data acquisition and visualization tool will be operational and tailored for ice hockey stride analysis. The optimization of data acquisition, analysis, communication, and visualization using a microprocessor will be demonstrated.

References

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