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iPhone sensor platforms: Applications to sports monitoring

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Abstract

The testing and monitoring of elite athletes in their natural training environment is becoming an area of interest to the sporting community. Specialised equipment is cumbersome and influences the training and analysis regimens athletes undertake to improve their performance. Ubiquitous and off-the-shelf versatile smartphones with advanced sensing capabilities can be applied to sports activity monitoring, providing a cost-effective means of widespread performance analysis. This paper briefly outlines the case for using these smartphones in sports monitoring applications, presents a model to collect data generated by these devices and presents the results of real-world usage when applied to cricket.

Keywords: Inertial sensor; database; iPhone; realtime

1. Introduction

Performance analysis of athletes in sport has traditionally been conducted in a controlled environment because of the need to use static or tethered monitoring equipment. With the advent of smaller, less obtrusive communication and sensing technologies, cumbersome and intrusive equipment can be replaced with lighter, low-profile equipment. Use of this new equipment can allow the athlete to move from a semi-static mode of analysis to a dynamic unconstrained real-world field environment, allowing the individual to perform his or her activities without interference from sensing equipment. An example of these less obtrusive technologies are inertial sensors which translate the physical movement of the device into linear (accelerometers) or radial (gyroscopes) measurements of inertia.

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Contemporary smartphone devices not only provide voice and data capabilities for the user, but also integrate sophisticated sensing technologies like accelerometers, magnetometers and GPS receivers all into a single off-the-shelf, aesthetic and user-friendly package. With intuitive multi-touch user interfaces allowing owners to quickly access information, and the availability of easy-to-download application distribution channels (eg. the iPhone 'App Store'), there is a greater opportunity for academically-researched techniques to cross into the commercial development. In this synergistic environment it is possible to reach a wider audience with software specially developed for monitoring activities, from providing feedback on sporting technique and performance, to providing the user pertinent health metrics like caloric intake and activity. It is estimated that smartphones will comprise up to 37% of the global mobile telephone market in 2012, up from the estimated 14% or 180 million units in 2009 [1], a year in which smartphones surpassed notebook devices in total shipped units. This rapid increase in the uptake of next-generation mobile devices spurs further innovation, packing more technology and sensing capabilities into smaller form factors for less.

In both sports activity and health-related monitoring endeavors, there exists the opportunity for the average smartphone user to get immediate feedback from coaches and health professionals who are remotely located away from the user based upon the data collected by the user's smartphone sensors. This ability to remotely collect data enables the user to incorporate feedback into their training regimen, improve their technique and moderate their activities to meet health outcomes. This can now become an accessible tool by any person who owns a smartphone.

Since the iPhone is such an accessible platform, they have been used in classifying the activity (the mode of transport) of iPhone users [2], and there have been various analyses [3, 4] of the specific platforms with regards to monitoring activity in users. In the past, specialized equipment has been required to monitor the activities of athletes [5], however these sensing devices require specialized technological knowledge to operate. This state of affairs implies that in using ubiquitous sensor platforms such as the iPhone, monitoring techniques previously developed and used in an academic setting can be brought into the wider community.

This paper will explore the various factors involved in the selection and function of the appropriate capabilities exhibited in smartphones for the purpose of activity monitoring. We will discuss how these features were selected on the basis of quantitative ability as well as delving further into the technological aspect in order to examine the real-time network requirements for remote activity monitoring systems. From there we present a design for a remote monitoring system and determine the effectiveness when used for the monitoring of complex sporting activities such as a bowler's action in cricket.

2. Smartphone Sensor Platforms

Modern smartphones are versatile devices with advanced sensing and communications capabilities, intuitive user interfaces and well-supported programming tool chains. Aside from their intended use as personal communicators and mobile assistants, these devices can be appropriated to serve as integrated sensor platforms for monitoring purposes. In selecting a device for our applications in recording real-time data from athletes on a sporting field, two primary requirements need to be met for the sensor platform to be useful: firstly it must be able to sense the individual's activities, commonly performed using inertial and location-based equipment; and secondly it must be able to transmit this data to another computer system via a standard wireless communications interface, typically Wi-Fi.

2.1. Communication

In order to evaluate an athlete in the field, it is important that all sensing devices communicate wirelessly to the coach (the *expert*), whether it be through a local area network or via the Internet. There are three types of applicable network technologies: Wide Area Networks (WANs) that communicate over a wide geographical range, Local Area Networks (LANs) that facilitates communication over a small geographical area, and the Personal Area Network (PAN) which has limited range and connects devices on the user or in the immediate vicinity. In sports monitoring situations, should the location of monitoring be outside of Wi-Fi (LAN) coverage, 3G WAN technologies could allow the remote collection of data from the device. However, if LAN infrastructure is in place then wireless Ethernet provides a simple and economic solution to the collection of athlete data in the field.

2.2. Sensors

Sensing is the other main requirement of the platform and must contain sensors capable of measuring position, movement and direction in order to determine what activity the user is performing.

Accelerometers can measure the dynamics of motion and position. Since the determination of acceleration alone is a difficult and complex task [6], other applications often use the accelerometer for short-term navigation and the detection of fine movement signatures and features (such as limb movement). Accelerometers can be used to determine orientation with respect to the earth's gravity as components of gravity are aligned orthogonal to the accelerometer axis. In a dynamic sports environment, complex physical parameters are measured and observed in relation to running and stride characteristics [7], and in the determination of gait [8]. One such application of determining characteristics is that of Cricket with activities such as the swinging of a Cricket Bat or the throwing action of a Cricket Bowler [5]. Once these characteristics are determined, the cricket player can receive feedback from his or her coach and improve their technique.

Researchers have also used accelerometers for determining physical activity and effort undertaken by subjects doing a number of commonplace activities [9]. These kinematic systems have been able to offer comparable results to expensive optical based systems [10], however many physical movements such as lower limb movement in sprinting, exceed the maximum specifications in commercially available units that are sufficiently small and inexpensive enough for such applications [11].

The most capable device for our activity monitoring needs is Apple's iPhone 4 [12] which contains a ±2g 3-Axis accelerometer, 3-axis gyroscope, magnetometer (digital triaxial compass), a user proximity sensor, ambient light sensor and a GPS receiver.

3. Remote Activity Monitoring

In monitoring the performance of athletes in the field, we must determine an applicable method of data transport in getting the athlete's performance characteristics back to the coach. Figure 1 illustrates the typical flow of information between the smartphone sensor platform (*client*) which streams sensor information to monitoring software (*server*). In the return path of information, the server streams feedback to the client or to any device capable of running a web browser. The ability to serve feedback via conventional HTML interface allows multiple parties to access and monitor the activities of the athlete.

The network topology defines the physical layout of the wireless network. This layout depends upon the number of devices to be monitored, the available network infrastructure and the transmit power of the network nodes. Wireless network topologies can be categorized into one of two types: a point to point ad-hoc network (*peer-to-peer*), or a centralized star network. This latter topology allows for multiple nodes to be simultaneously connected to a central router and the simultaneous monitoring of events from multiple data sources. In this case, the network nodes will be iPhones and/or other computing devices which connect to a central hub (wireless router). This layout has the advantage of increasing the range of transmission and easing configuration for multiple nodes, with the main drawback being that additional network infrastructure is required.

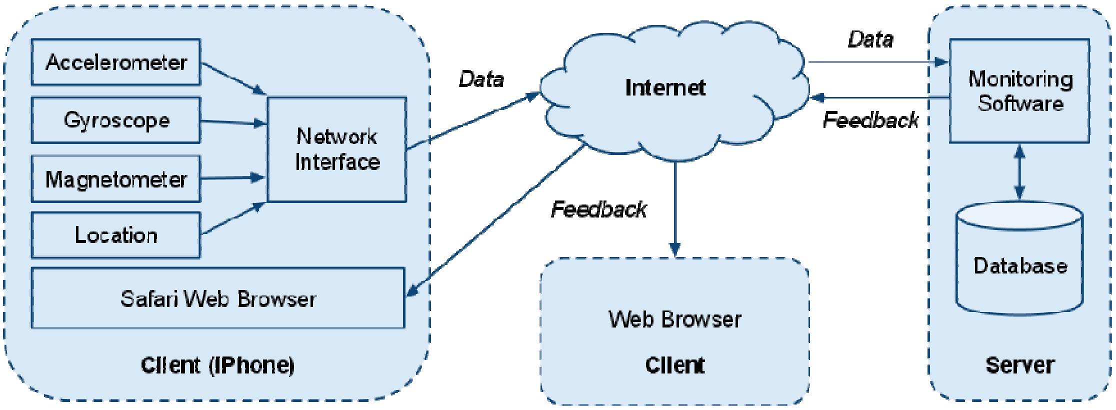

Fig. 1. Context-level diagram of a sports activity monitoring system

The network model describes how the network will be used by the nodes in the network, with the common models being centralized and decentralized [13]. For our application, the choice of the network model will be based upon the topology chosen, the flow of data and how the analysis is to be handled.

In the case of field sports monitoring, a star network would be appropriate as the network topology as it would allow a greater communications range and allow multiple simultaneous iPhone devices to stream sensor data. On this network topology a client/server model would be more appropriate as it would allow storage of the data on a laptop rather than on the limited memory of the sensing device. Additionally, a laptop can process and visualize the data in near real time such that a coach can monitor incoming sensor data in near real time during the sporting activity he or she is coaching.

4. Design of the Sports Activity Monitoring System

After selecting the sensor platform, the network topology and the model, we set forth to develop an activity monitoring system based around the iPhone. This system should process streaming sensor data generated from these devices in near real time via the Internet or a local wireless network. The basic concept can be seen in Figure 1. The system was developed as a database-driven network application and utilizes a client-server communications model to get data from sensing device to the network application.

4.1. Data Collection & Transport

To use the iPhone as an accelerometer-based sensor platform, a free open source application [14] acquired through the 'App Store' [15] was used to collect and transmit accelerometer data to the server via

Wi-Fi. At a rate of 50 Hz, this application records a triaxial accelerometer sensor measurement, a timestamp of when it was measured, and the device identification string of the iPhone.

4.2. Monitoring Software

We can see from Figure 1's server component of the diagram is designed for the reception and storage of accelerometer data from the iPhone application. The system can be decomposed into three main modules: the network interface exposed to the wireless network; the internal database interface which stores the accelerometer data alongside associated metadata; and the user interface which is used to manage, manipulate and redistribute the sensor data contained within the database.

As the iPhone accelerometer data streaming application exclusively supports streaming UDP sockets, a UDP interface manager was designed which automatically converted the incoming sensor data packets to an internal representation for database storage. This database also serves as the data source for an integrated MATLAB processing engine with which the user may apply feature extraction algorithms.

In order for the application to have real use by experts reviewing the accelerometer data in the field, there was a need to build a simple functional user interface. Through ASP.NET MVC and select Javascript algorithms, the user can review inertial and geolocation data collected by the iPhone, and the resultant output of any user scripts.

5. System Evaluation

In evaluating the developed monitoring software and to prove that using the iPhone yields comparative results to dedicated sensing devices, a series of tests of increasing activity complexity were performed using an iPhone located on the sacrum (lower back) of a test subject. The capabilities of the system were evaluated against specialized sensing hardware in compatibility.

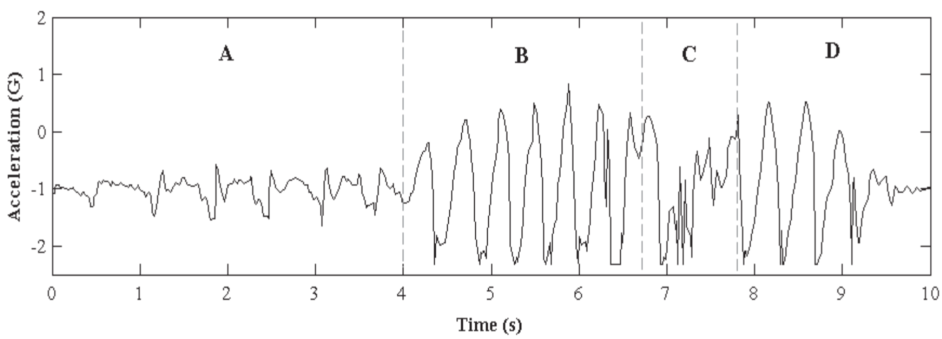

Fig. 2. Acceleration in Longitudinal Axis of Bowling Action

The action presented in Figure 2 is that of a fast bowling action found in Cricket. Phase A is the walking phase, with each step being periodic and easily identified. Phase B is the lead-up running phase, with a greater intensity than the previous walking phase. Phase C is the delivery phase, where the leading leg of the bowler is planted on the ground, which gives a noticeable spike. Finally, Phase D is the follow-through component of the action where momentum compels the body forward, similar to the action of Phase B. Of particular note is the device saturation during phases B and C, exceeding the nominated specification of ±2g plus tolerances for the accelerometer. In comparison with work previously done in evaluating bowling actions [5], we see that the capture of data is qualitatively similar and we reason that an iPhone is an appropriate substitute for a dedicated wireless sensing platform.

6. Conclusions & Future Work

This paper presents a model for a system that collects, stores and redistributes accelerometer data streamed wirelessly from an iPhone and asserts that commercial, off-the-shelf smartphone hardware does have a place in sports activity monitoring. In future research we aim to expand the capabilities of our monitoring software with an improved user interface, processing options and designing a customized iOS application that can further improve our results and give real-time feedback to the user. We also intend to further analyze the sensor and network characteristics of the iPhone platform in order to make a more qualitative characterization

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