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## Smartphones: Feasibility for real-time sports monitoring

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### Abstract

Sports monitoring technologies such as wireless sensor packages offer greater insight into the performance of athletes. The costs and complexities associated with these technologies can be prohibitive, particularly to sub-elite and amateur groups. Smartphones are a cheaper, more familiar technology with adequate capabilities for capturing many sports related activities. This paper shows the feasibility of smartphones for use in a real-time monitoring environment for sports applications. Capture of sports related activities is conducted using both internal and external sensors and the data used to identify key features of a cricket bowler delivery. The effects of distance, antenna orientation and body occlusion on signal strength are tested and show that real-time data can be reliably transmitted up to 100 meters. The power use of commonly used smartphone subsystems is used to calculate the minimum duration of a typical monitoring application and show that the lifetime is suitable for many sports. The benefits and challenges of using smartphones for these applications is also discussed, including those faced when utilising these devices across larger groups for real-time monitoring of teams.

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### 1. Introduction

It is of great interest to coaches and athletes to be able to examine athletic performance in real time and under natural conditions. In order to achieve this, wireless solutions such as sensor networks are required to minimise interference to the athlete. Commercial sensor suites are available, but the cost, complexity of use and highly targeted roles mean that their use is typically limited to high performance athletes.

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The embedded hardware of devices such as iPods and smartphones has shown promise for monitoring human activity in health [1] and sport [2] applications. While the hardware is not as specialised as dedicated sensor packages, the ubiquitous nature and variety of communications and sensor systems enables them to be easily and rapidly deployed in many roles without a steep learning curve or heavy cost imposed on the users. Some applications are targeted primarily at a single user for real-time collection and feedback of human activity, and the local processing and storage capabilities of smartphones have been shown to be well suited for these.

Athletic performance monitoring typically requires a coach or other expert to view collected data in order to provide effective feedback. While smart devices are capable of transferring data to remote systems such as laptops, their use in real-time, on field sports monitoring applications has not been widely explored.

This paper will demonstrate the feasibility of smartphones for real-time, on-field sports monitoring applications. Firstly, it will be shown that the collection of sports-related activities can be captured using embedded hardware and supplemented through external wireless sensors. Secondly, the reliability of streaming real-time data across the length of a typical field will be discussed. Thirdly, the battery capacity of smartphones under typical scenarios for monitoring athletes will be shown to be adequate for the duration of many sports. Finally, some of the faced during smartphone-based sports monitoring will be discussed at both the individual and group level.

## 2. Capturing data

The embedded sensors of a smartphone typically include tri-axial accelerometers for phone orientation and GPS for user position. Newer smartphones may also contain extra sensors such as gyroscopes and magnetometers. The sampling rate, range and accuracy of smartphone-based sensors allows for the capture of human activity in sporting applications on par with specialised sensor packages. To verify this, the acceleration profile of a cricket bowler was captured and streamed to a wireless router using iPods mounted on the arm and sacrum. While iPods aren't technically classified as smartphones, the embedded sensors match the capabilities of those used in iPhones and other devices. Figure 1(a) shows the output of the accelerometers during the run up and through the delivery. Each footstep taken during the run-up can be clearly identified, with the delivery stride appearing at 3.5 seconds and ball release at approximately 4 seconds.

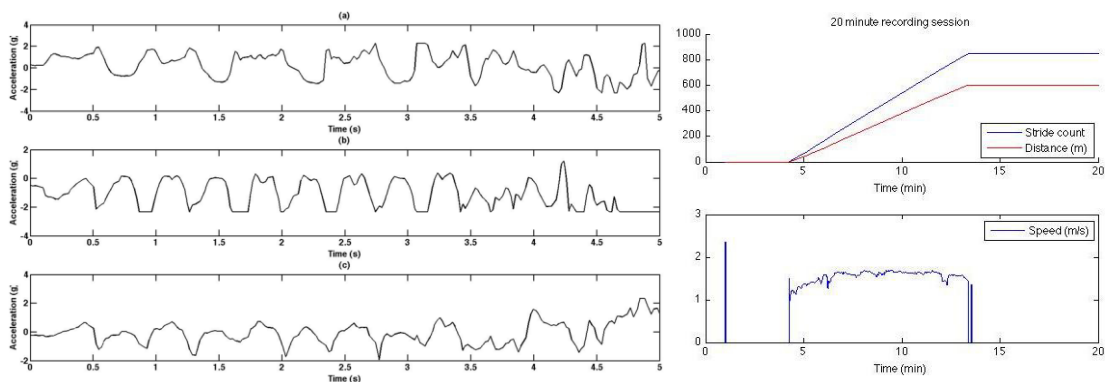


Fig. 1(a) Tri-axial accelerometer output from an arm mounted iPod at 50m from router, (i) anterior-posterior axis (ii) superior-inferior axis (iii) mediolateral axis with respect to torso (b) Real-time data transmitted from a footpod to smartphone during walk across field showing (i) detected stride counts (top line) and calculated distance (bottom line) and (ii) measured walking speed.

In conjunction with this embedded hardware, the number of wireless sensing devices is growing as the technology evolves. With Bluetooth a standard feature of smartphones, a significant number of these sensors are compatible for pairing and transmitting more detailed and varied information. Newer sensor-oriented protocols such as ANT and Bluetooth Low Energy are also finding their way into smartphones. These protocols have increased power efficiency and can support a much higher number of paired devices than the more commonly used Bluetooth protocol, essentially allowing the smartphone to perform as a centralised collection platform for personal and body area networks (PAN/BAN) [3].

To verify the application of these wireless sensors to capturing physical movement, a footpod using the ANT+ protocol was attached to a subject carrying a smartphone equipped with an internal ANT+ receiver. The subject walked around the field, with the output of the footpod transmitted to the nearby access point via the smartphone. Figure 1(b) shows the measured footstep total and walking speed as well as the calculated distance provided by the footpod. The footpod utilises accelerometers with similar characteristics to many smartphones and other sensor units, therefore it is deemed capable of capturing higher frequency events such as sprinting.

### 3. Transmitting data

In order to ensure that smartphones are suitable for transmitting real-time data from the field, it is necessary to characterise their behaviour under different conditions. Factors such as transmission distance, device orientation and occlusion effects of the body of the subject can all affect signal quality. To test these characteristics, an iPod running a signal measurement application was used in conjunction with a nearby access point. The site was a suburban cricket field. Other WiFi access points were within range of this site, but their signal strengths were considered too low to have any effect on the test.

The most important characteristic was the signal strength with respect to distance, to ensure data could be transmitted over the distance of a typical sporting field. Figure 2(a) shows the signal strength for various distances from the access point. As expected, the signal drops off in a manner consistent with near and far field radiation. What is important however, is that the signal strength even at the maximum distances measured is still sufficient for reliable data transmission. To verify this, the iPod was attached to a subject's arm who walked across the field. The accelerometer data shown in Figure 2(b) was streamed continuously from the device to the access point. The packet loss was monitored throughout the test and it was found that none were lost. The data clearly shows each peak corresponding to a footstep taken by the subject, with a jump performed at 40 meters and 80 meters from the access point.

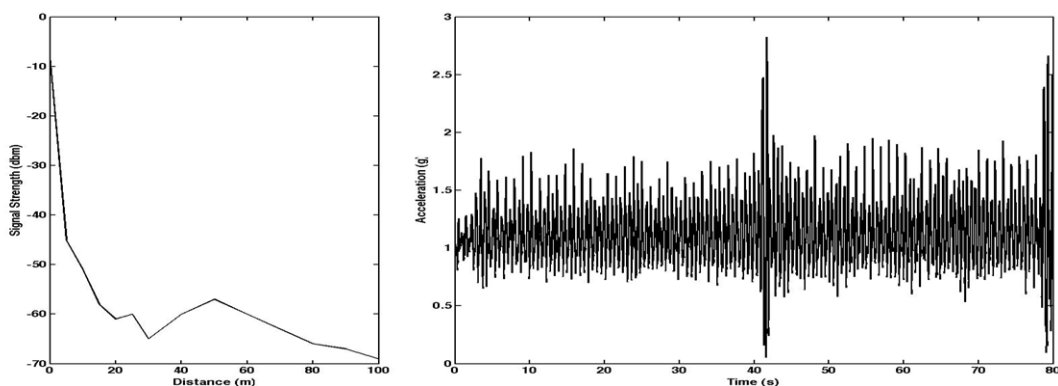


Fig. 2(a) Signal strength measured over distance from the access point (b) accelerometer output from an arm-mounted iPod, streamed continuously while walking across the field. Each footstep is clearly defined, with jumps performed at 40 and 80 metres.

The orientation of the device and occlusion of the subject can also affect the quality of the signal. Figure 3(a) shows the measured signal strength of the device for varying orientations at a distance of 10 meters and 50 meters. The iPod maintained a direct line of sight with the access point during this time. Minor changes in signal strength can be seen as the device is rotated, however the quality of the signal remains consistent with Figure 2(a). To observe the effect of body occlusion, Figure 3(b) shows the signal strength that was measured using iPods on the subject's arm and sacrum at a distance of 20 meters from the access point. It can be seen that there is an appreciable drop in strength owing to the body absorbing some of the signal, however it is still sufficient for reliable data streaming.

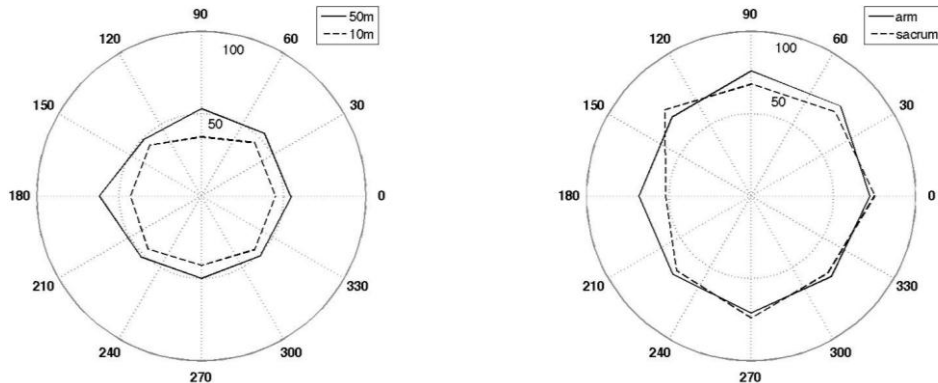


Fig. 3. Radiation Pattern (signal strength for different angles) with (a) direct line of sight to router at different distances and (b) with body occluding path to router at 10m.

#### 4. Battery life

Typical field sport applications will utilise a number of different measurement and transmission technologies. In the context of smartphones, these systems will generally include GPS for position tracking, wifi for transmission, embedded accelerometers and external sensors based on a low power protocol i.e. Bluetooth. Each of these systems require a certain amount of power to operate, in addition to the base level consumed by the phone in its idle state. With battery capacity considered a major bottleneck of smartphone technology [4], it must be determined if the device can operate for the duration of a match in order to avoid replacing the battery or the entire device periodically. Battery capacity and consumption will vary between each make, model and individual device, and utilisation of subsystems will vary among applications. This variability makes it difficult to provide specific timeframes, however it can still be shown that worst case, high usage scenarios will meet the minimum requirement of many field sports. Table 1(a) outlines the measured current drawn by a smartphone during idle state (screen off, cellular active) as well as the individual contributions of typically used features. The consumption for transmission using WiFi [5] and receiving data using Bluetooth [6] are also included from external literature. When determining a total value the display consumption was ignored as it can be assumed to be off during use. A 25% increase in overall consumption is applied to cover variations in hardware configurations.

From these values it can be concluded that the battery capacity of typical smartphones is sufficient for supporting collection and monitoring applications for many sports. Evolving technology, higher capacity batteries and more efficient communication protocols will allow monitoring of longer duration sports or increase the amount and variety of data by incorporating other hardware.

Table 1(a) Consumption of typical smartphone subsystems used for activity monitoring (display excluded from total). 25% variation is added for ‘worst-case’ usage (b) Common smartphone battery capacities and their respective duration when drawing 354.63mA.

|                              | Measured current (mA) | Capacity (mAh) | Duration (hours) |
|------------------------------|-----------------------|----------------|------------------|
| Phone idle                   | 21                    | 1100           | 3.1              |
| Display(max)                 | 117                   | 1420           | 4                |
| GPS (active)                 | 45.7                  | 1650           | 4.65             |
| WiFi (Tx)                    | 170                   | 2100           | 5.9              |
| Bluetooth (Rx)               | 47                    |                |                  |
| Total                        | 283.7                 |                |                  |
| <b>Total + 25% variation</b> | <b>354.63</b>         |                |                  |

(a)

|  | Capacity (mAh) | Duration (hours) |
|--|----------------|------------------|
|  | 1100           | 3.1              |
|  | 1420           | 4                |
|  | 1650           | 4.65             |
|  | 2100           | 5.9              |

(b)

## 5. Discussion

Smartphones and similar devices such as iPods have some advantages over specialised sensor packages. Their ubiquitous nature and the simplicity of downloading software means that they can be readily purchased for deployment or replacement. This has a particular benefit to amateur sporting groups, as many people currently own a smartphone. By taking advantage of this, these groups can avoid the costs associated with technology infrastructure and receive the benefits of a real-time monitoring application. The range of embedded communications hardware also allows for highly customisable applications. As newer sensors are developed and released, they can be easily integrated directly into an established configuration.

However, since smartphones are not purpose-built for these applications, factors such as wearability become significant. Wireless sensors are generally lightweight and designed for placement on specific parts of the body. The size and weight of smartphones generally limits their placement to the torso or upper arm to minimise interfering with the player’s movements. Many sports related activities can still be captured from these locations, especially in conjunction with wireless sensors.

The feasibility of smartphones for real-time sports monitoring has been demonstrated for individual athletes. It has been shown that useful data can be captured and streamed from an athlete to a remote system for the duration of many sports. The next step in this process is to incorporate real-time monitoring of multiple athletes simultaneously for use in team sports. This brings a new set of challenges that must be addressed.

With a large number of devices in close proximity communicating under the same protocols, interference can cause severe degradation of signal quality. This can occur at both the sensor/phone and phone/access point levels. Sensor-oriented protocols such as ANT+ and Bluetooth 4.0 employ a technique known as frequency agility that monitors interference and switches to a different frequency automatically. For wifi transmission, novel methods are being developed to address this issue [7].

It was shown previously in this paper that data could be transmitted reliably over distance when a human body is blocking direct line of sight between the transmitting device and access point. When a larger number of players are grouped together, the resulting occlusion will be significant enough to reduce the transmission range below the required distance. Placing a number of access points around the field can alleviate this issue at the expense of increased hardware costs and complexity.

Storing, processing and presenting data for a single athlete is well within the capabilities of modern computers. However, when this is multiplied by the number of players in a team, the amount of data can

be overwhelming to both the computer and the person viewing the data. Therefore efficient techniques are required for both fast analysis and presentation. The onboard processing power of smartphones can be utilised to reduce the volume of data prior to transmission to the server.

## 6. Conclusion

This paper has demonstrated the feasibility of real-time monitoring using smartphones by showing that sports related activities can be captured using both embedded systems and external sensors and transmitted wirelessly across sufficient distances. The battery capacity of smartphones has also been shown to be adequate for many sports. Team sports pose a greater challenge due to the larger number of devices operating within close proximity as well as the significant amount of data generated. Future work is intended to further address the issues raised when scaling wireless technologies into larger, team based environments. Methods for highlighting and reducing power consumption will also be explored to extend monitoring time for use in longer duration sports.

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