The application of wireless technology and sensors for sporting applications

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Advances in technology today have influenced and changed many aspects of our lives. As technology becomes smaller it is able to be used in more and more aspects of our daily lives, competitive and recreational sports are no exception. Borrowing from many disciplines athletes today are clad in space age clothing, ride aerospace and automobile inspired bicycles and use high tech racquets built from composite and other ‘high tech’ materials. Often accompanying each athlete today are complex watches and heart rate monitors that just a few years ago were the province of only our elite sports academies and athletes. As we enter the age of wireless communications pervading our everyday lives and an unquenchable thirst for information, the dream of small unobtrusive monitoring devices that can quantify every aspect of an athlete’s performance in real time is becoming a reality. One day athletes will no longer need to go to specialist laboratories for performance assessment but instead wear widely available devices during everyday training and perhaps even in competition. This paper outlines some of the recent developments in monitoring technologies and the implementation of wireless solutions. Aspects such as human comfort, power consumption, antenna design, choice of frequency band and some examples will be discussed.

SENSORS

Sensor technologies today borrow heavily from many industries, in particular mass-market products such as automobiles and personal communications devices have made many devices available to sporting applications at reasonable prices. Table 1 below lists a number of sensors suitable for use in sporting applications. The relative cost and portability are important considerations when considering them for application. Ease of integration and signal conditioning are also very important considerations.

Thus in general the sensors themselves represent only a small proportion of the complexity and cost when compared to the sensor support system.

Table 1: Sensor types and Technologies

<table>
<thead>
<tr>
<th>SENSORS</th>
<th>INTERFACE</th>
<th>COST</th>
<th>PORTABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain gauge</td>
<td>Physical</td>
<td>LOW</td>
<td>GOOD</td>
</tr>
<tr>
<td>Load cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerometer</td>
<td>Electrical</td>
<td>LOW</td>
<td>GOOD</td>
</tr>
<tr>
<td>Gyroscope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>Physical</td>
<td>MED</td>
<td>FAIR</td>
</tr>
<tr>
<td>BP type</td>
<td>Physical</td>
<td>LOW</td>
<td>POOR-FAIR</td>
</tr>
<tr>
<td>Thermistor</td>
<td>Low</td>
<td>FAIR-GOOD</td>
<td></td>
</tr>
<tr>
<td>SCR</td>
<td>Electrical</td>
<td>LOW</td>
<td>FAIR-GOOD</td>
</tr>
<tr>
<td>EGG</td>
<td>Electrical</td>
<td>MOD-HIGH</td>
<td>FAIR-GOOD</td>
</tr>
<tr>
<td>ECG</td>
<td>Electrical</td>
<td>MOD</td>
<td>GOOD</td>
</tr>
<tr>
<td>EMG</td>
<td>Electrical</td>
<td>LOW</td>
<td>GOOD</td>
</tr>
<tr>
<td>EOG</td>
<td>Electrical</td>
<td>LOW</td>
<td>GOOD</td>
</tr>
<tr>
<td>MEG</td>
<td>Non-contact</td>
<td>VHIGH</td>
<td>POOR</td>
</tr>
<tr>
<td>MCG</td>
<td>Non-contact</td>
<td>MOD-VHIGH</td>
<td>POOR</td>
</tr>
<tr>
<td>Optical</td>
<td>Non-contact</td>
<td>LOW</td>
<td>GOOD</td>
</tr>
<tr>
<td>Absorption</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SENSOR SYSTEMS

Physiological and other sensors usually require some form of interface to facilitate their intended function. The nature of this interface varies widely depending on the type of sensor as well as its intended application. Utilization of a sensor platform greatly simplifies the process of measuring a physical event and turning it into something useful (Figure 1) by providing, support for the sensor, basic signal conditioning, storage, data transmission and application specific processing of the data. In the case of sporting applications this modular approach allows rapid customisation and modification. Thus technical expertise, understanding and expectations of sport scientists can be accommodated. For example accelerometers when combined in such a system have enabled the recording of athlete activity and the storage and/or transmission of data.

Figure 1: The role of the sensor platform in sensing applications

In such a platform used widely in our research group it supported the acquisition and processing of tri-axial accelerometers at or above 250Hz per channel. Data acquisition, basic processing, data transmission and storage was handled by a scheduler based Operating System on a 16MHz microprocessor. Depending on the exact application, input from other sensors was also incorporated.

In each case the customized sensor platform was packaged according to the environmental demands of the sport and where appropriate near real time transmission or display of the data was available for coach and athlete feedback.

WIRELESS NETWORKS

Real time feedback has great value in the coaching and training environment and has been greatly facilitated by the advent of low cost wireless technologies. Wireless technologies have advanced considerably in recent years giving rise to many communications protocols that target different balances between throughput, power consumption and complexity. Many of these protocols are open standard whilst many others are vying for market share with competing manufacturers.
Wireless networks allow communication between sensor nodes and host systems, which are unable to be networked via traditional wired means. A wireless network of sensor nodes can be deployed quickly and easily, allowing near real time feedback of collected data. A wireless network appropriate for sensing applications must be able to handle the required data throughput, support the required number of nodes and use a minimum amount of power to conserve battery life. Wireless sensor networks that are deployed on mobile objects must be able to cope with temporary data dropouts and must be able to reconfigure the network where appropriate.

Wireless sensor networks are different from traditional wireless ad-hoc networks. Ad-hoc networks are designed to be created "on the fly" with any number of unknown nodes and are typically used for data transfer between any of the nodes. Wireless sensor networks are typically deployed with a known number of nodes, with each of the nodes being known prior to network initialisation. The nodes usually don't need to communicate with each other; they are usually used to collate the data in a central location for analysis. Wireless sensor networks should be designed with these things in mind, to ensure optimum network performance.

Wireless sensor networks can have a number of configurations and are either designed to directly send data back to a fixed receiving node (single hop networks) or can adopt a mesh networking style topology where the data is routed back to a fixed receiving node via multiple mobile sensor nodes (multi-hop network). Single hop wireless sensor networks are typically easier to set up and maintain, however they limit the range of the wireless sensor network to a single radio link. Multi-hop networks have the provision for a greater number of sensor nodes and allow greater sensing ranges to be achieved, but are much more complicated to implement. Routing nodes in a multi-hop network can find a new path if an individual node drops out. Configuration, such as limiting the number of routing nodes, multiple redundancies and reducing network overhead such as re-configuration time are important considerations.

WIRELESS NETWORK DESIGN

There are essentially two approaches to implementing a wireless network. Utilising off the shelf existing wireless protocol solution or custom design a wireless protocol for the specific application. Existing protocols reduce the development time of a wireless sensor network considerably and more time can be dedicated to analysis of the retrieved data, however custom design can create a more specific and hence better overall solution. Given project lifespan for many research endeavours it is likely that any chosen technology will be updated and out of date or obsolete by the time any working network is complete. This is an important consideration when choosing to back either a stable technology from a well known manufacturer or go with cutting edge technology from a small start-up company, whether to design your own protocol and have to repeat the process regularly or go with something existing that will continue to be developed by manufacturers.

Existing wireless protocols can again be broken up into two different categories; global standards ratified to a standards body and proprietary wireless networks implemented by a single company. The risk of using proprietary radio standards to implement a wireless sensor network solution is that support and supply of radios can be limited as only one company produces them. The ratified standards are passed by members from many companies which ensure that the specification is robust and usually ensures that many vendor options are available.

The Institute of Electrical and Electronics Engineers (IEEE) Standards Association has ratified three different categories of wireless network standards; IEEE 802.11 Wireless, IEEE 802.15 Wireless Personal Area Networks (WPANs) and IEEE 802.16 Broadband Wireless Metropolitan Area Networks. The IEEE 802.11 and IEEE 802.15 wireless standards are designed for wireless local area networks (WLANs) and wireless personal area networks (WPANs) respectively and are suitable for wireless sensor network applications. The IEEE 802.16 wireless standards are designed for wireless wide area networks (WWANs) and are not so suitable for wireless sensor networks due to the unnecessary high throughput and high power requirements. A comparison of the relevant standards is provided in Table 2. Figure 2 shows a comparison of the standards for range and throughput. This is a useful aid in determining what protocol might be most useful. Careful consideration to antenna use, power requirements and operating time also are important factors as battery size is often much larger than the instrumentation and sensors combined.

There are many elements to consider when implementing a wireless network. Issues such as node limitations, required range, antenna choice and power restrictions must be considered to create a successful wireless sensor network. A brief introduction to these issues is presented in this section.

WIRELESS TRANSMISSION

Once the range requirements of the wireless sensor network have been determined the required transmit power can be determined. The free space path loss equation demonstrates the loss due to beam divergence. It is a good approximation of how much loss occurs for a given transmission path for a specific transmission frequency. The free space path loss equation appears below as equation (1). This equation only determines path loss due to beam divergence, the losses associated with dispersion and absorption by the atmosphere are not included in this equation.

$$\text{Path Loss} = 20 \times \log_{10} \left( \frac{4 \times \pi \times d}{\lambda} \right)$$

(1) [ii]

Where:

- **Path Loss** = Power loss (dB)
- **d** = Distance (m)
- **$\lambda$** = Wavelength (m)

The equation shows that as the transmission path distance is increased the associated path loss also increases meaning a lower signal to noise ratio (SNR) at the receiver. This results in a lower data throughput for the link as the probability of error per bit is increased.

Rather than increasing the transmitted power, the path loss can be overcome by the use of directional antennas. By directing more of the transmitted power at the receiver the SNR is once again increased and the wireless link can operate at the desired throughput. Antenna directionality is measured in decibels by comparing the radiation pattern with that of a half-wave dipole antenna (quoted as dBi) or compared with a theoretical isotropic radiator (quoted as dB). Using the Friis transmission formula equation (2) we can calculate the power received at the receiver taking into consideration the path loss and the effect of directional antennas. If this received power is above the receiver sensitivity of the receiver then the link will operate successfully. The amount of
surplus power received above the specified receiver sensitivity is known as the fade margin and ensures that the link will still operate if conditions deteriorate.

\[ P_{Rx} = P_{Tx} \left( \frac{G_{Tx} \times G_{Rx} \times \lambda^2}{16 \times \pi^2 \times d^2} \right) \]  

(2) [iii]

Where:

- \( P_{Rx} \) = Received Power
- \( P_{Tx} \) = Transmitted Power
- \( G_{Tx} \) = Gain of Transmitting Antenna
- \( G_{Rx} \) = Gain of Receiving Antenna

REGULATORY REQUIREMENTS

Communications in wireless sensor networks typically operate in one of a number of unlicensed communications bands such as the Industrial, Scientific and Medical (ISM) bands. Some example frequencies are 433MHz, 900MHz, 1.8GHz and 2.4GHz. Communications in these frequency bands must conform to strict transmit power and bandwidth guidelines that are regulated by each country's government regulatory bodies. Communication restrictions in the unlicensed bands vary from country to country and before a wireless network is set up it is necessary to research the relevant communication laws.

Something as simple as changing the antenna on a wireless communications module can cause a wireless network operating within the legal guidelines to breach the power regulations set for the unlicensed band. Communications in the unlicensed band are governed by the ACMA (Australian Communications and Media Authority) in Australia [iv], the FCC (Federal Communications Commission) in the USA [v] and the ARIB (Association of Radio Industries and Businesses) in Japan [vi]. Because of the emerging popularity of RF devices many of these regulations are under revision.

POWER SUPPLY ISSUES

Once the range requirements and transmission power are determined a suitable power source must be selected. This power source must be small enough for the desired application and must be able to provide the required power for the desired period of operation.

Depending on the wireless sensing application power scavenging techniques can be employed that will extend the sensor platforms period of operation and in some cases even power the platform completely. Examples of power scavenging systems include solar panels for harnessing solar energy [vii], magnetic transducers for harnessing vibrational energy [viii] and Piezoelectric transducers for harnessing vibrational energy [ix].

The period of operation can also be greatly increased by selecting a wireless network technology that utilises low power modes of operation. The majority of power in a wireless sensor network is used by the radio transceivers. Putting these in a low power state or even shutting them down for period of time greatly increases the sensing time of the wireless node.

NETWORK SYNCHRONISATION

Synchronisation of data between wireless sensor nodes is critical to get an accurate analysis of a wireless sensing environment. Time stamping of the sensed data ensures that once the data is collected and collated the various sensor nodes data is synchronised. Packet time stamping may already be implemented depending on which wireless technology was chosen to implement. A TCP / IP based IEEE 802.11 network may already implement time stamping of the packets as part of the TCP / IP standard. If this is not the case a real time clock can be added to the wireless sensing platform and the time value can be added to the wireless sensing data when transmitted over the wireless sensor network. In this scenario it is critical that clock synchronisation packets be transmitted periodically to ensure synchronisation between clocks on each wireless sensing node.

WIRELESS POSITIONING SYSTEMS

A wireless network of sensor nodes allows near real time monitoring of multiple parameters on multiple objects. Using the wireless network to estimate the position of the sensor platforms allows the data to be cross-correlated with spatial information. There are four main methods of estimating the range of a wireless node; Received Signal Strength (RSS) [x], Time of Arrival (TOA) or Differential Time of Arrival (DTOA) [xi] and Angle of Arrival (AOA) [xii]. Once the range of the device has been determined by a number of fixed nodes the position can be estimated by a simple triangulation calculation. This estimated position can be improved by averaging the position over a number of measurements or by using a more advanced technique such as using an extended Kalman filter [xiii] or the method of least squares [xiv].

Using the received signal strength (RSS) to estimate the range of a device relies on the power path loss that occurs between the transmitter and the receiver. This estimated range is substantially affected by interfering objects, as the range estimated will be much larger due to the extra path loss.

A time of arrival (TOA) based positioning system estimates the range of a device by measuring the time taken for the receiver to receive the transmitted signal. By using this time and the speed of electromagnetic propagation in air the range of device can be calculated. This system relies on extremely accurate measurement of the time difference between positions. Even a small error in time can cause a huge error in the estimated position of the receiver.

Angle of arrival (AOA) positioning systems measure the direction of the transmitting device. The device position can then be estimated using trigonometry. The problem with AOA systems is accurately determining the direction of the transmitter. One method of determining the transmitter direction is to use a mechanically steered antenna or electronically steered smart antenna with a narrow beam.

CONCLUSIONS

The use of sensors for monitoring of sporting activities is an emerging area of investigation. Whilst many suitable sensors exist as commercial products, the electronic support systems for signal conditioning, processing and storage are not easily available. Such a system has been described. This sensor system also utilises wireless technology to allow near real time access to data.

The use of wireless technology is a rapidly developing field, in this paper several technologies and standards have been presented for consideration. Basic calculations and guideline for their use have also been described. Inherent limitations have been introduced and the application of locating techniques has also been discussed, which are ideal to use in indoor and other environments where GPS based solutions are unable to be used.
Figure 2: Typical range and maximum throughout of several available wireless network technologies

Table 2: Wireless Protocol Summary [xv, xvi]

<table>
<thead>
<tr>
<th>Network Property</th>
<th>IEEE 802.11a</th>
<th>IEEE 802.11b</th>
<th>IEEE 802.11g</th>
<th>Bluetooth / IEEE 802.15.1</th>
<th>ZigBee / IEEE 802.15.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Band</td>
<td>2.4 GHz</td>
<td>5.8 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Technology</td>
<td>DSSS</td>
<td>OFDM / 64QAM</td>
<td>OFDM / DSSS</td>
<td>FHSS / GFSK</td>
<td>O-QPSK</td>
</tr>
<tr>
<td>Required System</td>
<td>1MB+</td>
<td>1MB+</td>
<td>1MB+</td>
<td>250KB+</td>
<td>4-32KB</td>
</tr>
<tr>
<td>Resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughput</td>
<td>11 Mbps</td>
<td>54 Mbps</td>
<td>54 Mbps</td>
<td>723.2 Kbps</td>
<td>250 kbps</td>
</tr>
<tr>
<td>Range</td>
<td>100m</td>
<td>100m</td>
<td>100m</td>
<td>100m (CL 1)</td>
<td>75m</td>
</tr>
<tr>
<td>Power Usage</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Maximum Nodes</td>
<td>254</td>
<td>254</td>
<td>254</td>
<td>8</td>
<td>65536</td>
</tr>
</tbody>
</table>
REFERENCES


[iii] H. T. Friis, A note on a simple transmission formula, in Proc. IRE, 1946, p.34]


[xvi] IEEE Computer Society, 802.15.4 IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements, Part 15.4: Wireless Medium