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Wearable Wireless Inertial Measurement for Sports Applications

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Abstract: A wearable WIMU (Wireless Inertial Measurement Unit) [1] system for sports applications based on Tyndall's 25mm mote technology [2] has been developed to identify tennis performance determining factors, giving coaches & players improved feedback [3, 4]. Multiple WIMUs transmit player motion data to a PC/laptop via a receiver unit. Internally the WIMUs consist of: an IMU layer with MEMS based sensors; a microcontroller/transceiver layer; and an interconnect layer with supplemental 70g accelerometers and a lithium-ion battery. Packaging consists of a robust ABS plastic case with internal padding, a power switch, battery charging port and status LED with Velcro-elastic straps that are used to attach the device to the player. This offers protection from impact, sweat, and movement of sensors which could cause degradation in device performance. In addition, an important requirement for this device is that it needs to be lightweight and comfortable to wear. Calibration ensures that misalignment of the accelerometer and magnetometer axes are accounted for, allowing more accurate measurements to be made.

Key words: Inertial Measurement, Tennis, Wearable, Wireless

1. INTRODUCTION

TennisSense is a joint project between the Science Foundation of Ireland (SFI) funded CLARITY Centre for Sensor Web Technologies and Tennis Ireland - the National Governing Body for the sport of tennis in Ireland - with the aim of developing a sensing platform to digitally capture physical, tactical and physiological data from tennis players in order to assist in their coaching and improve their performance. A major part of this joint project involves the capture and analysis of relevant kinematic motion data from the tennis players. This data will then be used to characterise a player's technique in order to provide accurate, quantitative feedback on player performance in near real time. To achieve this, devices that can capture the kinematics of an athlete during a tennis match are required.

Tyndall was tasked with the creation of a wearable wireless inertial measurement gathering system suitable for use in the TennisSense project and possible future applications. The system would have to be able to accurately and simultaneously capture 6 Degree-of-Freedom (6-DoF) motion data at several locations on a tennis player over the full range of human motion. In addition the system would require a high sample rate, whilst remaining small, robust, lightweight, low power and not impeding or restricting the motion of the tennis players. Although the system is based on existing Tyndall 25mm mote technology, a significant amount of additional work was required to meet the specific requirements of the TennisSense application.

This paper details the motivation for and the development of the above TennisSense system, outlining details on the device requirements, system architecture and design methodologies. A short discussion of the difficulties encountered in the course of developing and prototyping these devices and how these difficulties were overcome; further comments on future work are also presented.

2. MOTIVATION

There are many reasons for developing such a wearable WIMU based system like that used in this project. One of the principal motivations is to develop a simple, accurate, high performance and lower cost alternative to traditional motion capture systems. These generally require special suits, expensive high speed cameras, labour intensive setup and calibration.

The realisation of such a system will allow for a nearly universal, modular, easily deployable motion capture and analysis system. This system could then be used to provide real time quantitative feedback to athletes and coaches during training. It would also be possible to monitor performance levels over longer periods of time and recognise and characterise sports actions from analysis of kinematic data. Furthermore, this system could greatly increase the consistency and effectiveness of coaching, sports training and exercise programs, which could help in producing better athletes. The recorded information would also be a valuable source of quality bio-kinematic data for analysis by sports scientists and physiotherapists. If such a system can be realised it may find uses in training and coaching for other sports as well as areas such as human health monitoring, physical rehabilitation, machine positioning, asset and animal tracking.

3. DESIGN

It was decided to use Tyndall's existing stackable 25mm mote technology in order to realise a low cost system in a timely manner. These have been used extensively by researchers in Tyndall and many outside bodies for several years and offer a quick and cheap option for creating compact prototype electronic devices. The Tyndall mote technology consists of a range of small, stackable electronic communications, computing and sensing elements called layers. These are generally based on a 25x25mm footprint circuit board and have connectors on the top and bottom along two sides. Many different classes of mote layer exist such as: transceiver layers, environmental sensor layers, interface layers, power delivery layers, etc. Several inertial measurement layers have also been developed for different projects. These generally consist of accelerometer, gyroscope and magnetometer type sensors, each with 3-axes of sensitivity, orientated so that the 3-axes of sensitivity of each type of sensor are mutually orthogonal. By combining the outputs of each sensor, full 6 Degree-Of-Freedom motion data can be obtained.

By combining several different mote layers, more complex systems can easily be realised. To achieve the basic functionality of a WIMU, a prospective device requires elements for sensing motion, processing of data, transmission of data and the supply of power. At the beginning of the project, the specifications required for the WIMU device were unknown. In order to get a better idea of what specifications would be required, an initial prototype device was urgently needed for testing. The modular nature and range of existing layers available for the Tyndall 25mm mote platform allowed a device to be assembled and delivered almost immediately, meeting this urgent need for an initial test platform. This modular nature also allowed further versions to be rapidly developed.

3.1. System Requirements

The WIMU devices also had to meet or exceed several application specific requirements which are outlined below.

- Have a robust and well sealed device packaging to protect device circuitry
- Have a sufficiently large sensor range to capture a tennis player's movements
- Have a sufficient sampling rate to capture tennis player's movements in detail
- Provide consistent and accurate sensor output
- Be lightweight, small and ergonomic

The system also requires that several WIMUs operate concurrently, at various locations on a tennis player to record sensor data and calculate 6-DoF motion data at each location before wireless transmission to a PC/laptop via a master device or base unit. Further processing and fusion of these IMU data with data from other sensors placed on athletes or on a specially instrumented tennis court could be performed on the computer. To accurately monitor player movement, a WIMU is required on the serving wrist, lower serving arm, upper serving arm, chest and pelvis. Therefore, the required number of WIMUs is five, as shown in Fig. 1. A sampling rate in the hundreds of hertz was also requested so that the data would be comparable to that obtained from camera based motion capture systems which normally operate in the hundreds of frames per second range.

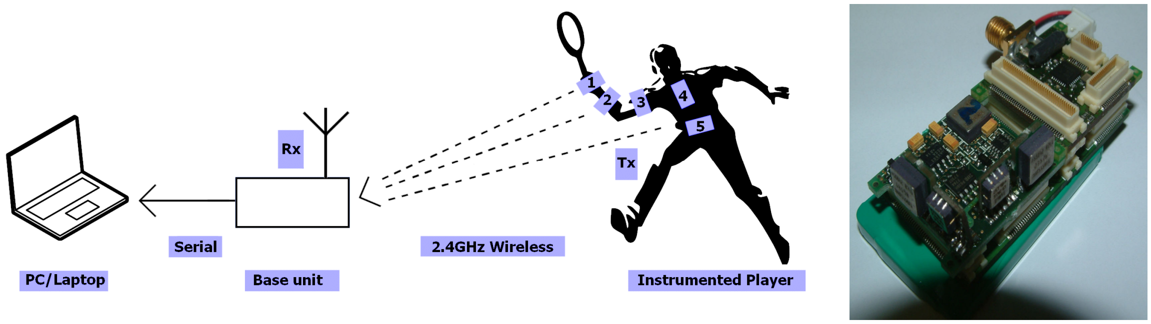

Figure 1. Schematic of TennisSense system architecture (left), Initial prototype test unpackaged device (right)

3.2. Initial Prototypes

An early prototype WIMU device (shown in figure 1) was delivered to researchers at Tennis Ireland, DCU and UCD for initial testing and data gathering. This device consists of: an IMU layer with multiple MEMS inertial sensors (Table 1), a combined microcontroller and 433MHz radio transceiver and antenna for data communication with a base station and connected PC. In addition, a power supply and interconnect layer with supplemental high-g accelerometers (Table 1) is also employed.

Table 1. Specification of Rev1.7 IMU layer

	Initial Prototype WIMU	
Sensor Type	**Part name**	**Range**
Accelerometer	ADXL202E	+/-2g
Gyroscope	ADXRS150	+/-150°/s
Magnetometer	HMC1052	+/-6Gauss
Supplemental Accelerometer	ADXL278	+/-70g

3.3. Initial Testing

Tests were performed at Tennis Ireland's campus by DCU based CLARITY members, using the initial devices described above, worn by a professional tennis player. It was discovered during testing that the outputs of the inertial sensors were seen to frequently saturate during sudden player movements such as serves and shots, which indicated that their sensing range was too small as can be seen in figure 2. A modification to increase the range of the gyroscope sensors used in the initial prototypes was performed, although saturation was still occasionally observed.

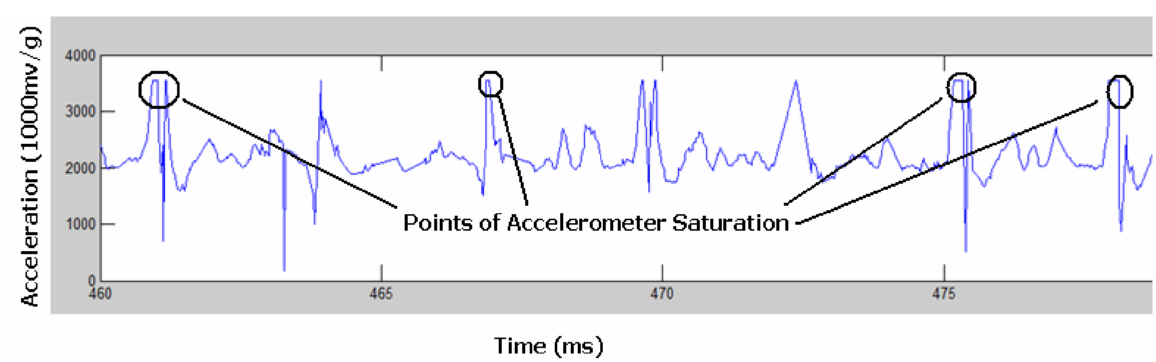

Figure 2. Accelerometer saturation in testing of initial prototype device

To solve this problem of insufficient range the accelerometer and gyroscope sensors need to be replaced with new sensor components with a greater range. Additional effects of latency were also observed during testing and this was attributed to the limited radio throughput of the 433MHz radio, it was determined that a faster wireless transceiver would be required in future. More robust packaging solution providing easy charging, a power switch and status LED was also requested.

Table 2. IMU specifications for various WIMU devices

	IMU Sensor Specifications			
Sensor Type	**Initial Prototype**	**Modified Prototype**	**Requested Spec**	**TennisSense WIMU**
Accelerometer	+/-2g	+/-2g	+/-4g	+/-10g
Gyroscope	+/-150°/s	+/-600°/s	+/-2000-3400°/s	+/-1200°/s
Magnetometer	+/-6G	+/-6G	N/A	+/-6G

4. CONCLUSIONS & NEW DEVICE

Initial prototypes - despite providing valuable data - were not capable of providing a sufficiently wide sensor range, sufficiently high sampling rate or satisfactory robustness. To provide a sufficient radio throughput to allow high sampling rate data transmission, the radio transceiver used in the next WIMU system will be a 2.4GHz Nordic nRF2401. This device transmits data at up to 1Mbps, which is 20 times that of the initial prototype's 433MHz devices. This higher data rate combined with code optimisations on the device will allow increased sample rate with more reliable transmission of data. New inertial measurement sensors with a wider range than those used in the initial prototype devices have been sourced. Sensors that are pin compatible with the existing device were chosen, offering a quick upgrade path to a higher spec TennisSense WIMU. A robust, well sealed ABS housing with Velcro-elastic arm straps and easily accessible charging port, power switch and status LED has also been designed to improve the overall reliability of the WIMU devices.

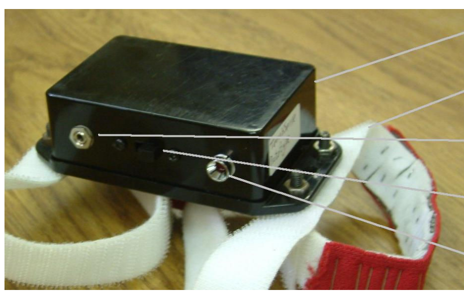

Figure 3. Packaged TennisSense WIMU with nRF2401 radio and higher spec inertial sensors

5. FUTURE WORK

Assembly of additional TennisSense WIMUs devices for further testing is required to confirm that a system with multiple WIMUs operating concurrently performs as expected. These will then be calibrated and assembled into protective device packaging before delivery to Tennis Ireland where they will be for further testing with tennis players and sports scientists. Future TennisSense WIMU devices are also planned which will have even wider sensor ranges, smaller overall size and lower power requirements.

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