5th Asia-Pacific Congress on Sports Technology (APCST)

# An unobtrusive swimming monitoring system for recreational and elite performance monitoring

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## Abstract

Swimming is one of Australia's most successful sports at international competition. This success is due to the elite level support provided at Australia's sports academies and institutes, together with strong recreational and developmental programmes. In recent years Australia's approach to elite level sport has been somewhat eroded as other countries adopt our processes, coupled with a shrinking talent pool nationally. Since early 2000 a technology initiative has been undertaken to help address this by offering a way to provide elite level support at the local level. Swimming assessment is traditionally a labour intensive process where stroke phase, stroke rates, stroke counts, and lap times are often manually recorded or extracted from video data. This manual process is dependent on high staffing levels and is generally unavailable for routine training activities or remote areas. Beyond the basic measures above the coordination of key body segments in swimming is of growing interest for swimmers and coaches though it is difficult to obtain. Understanding these movements can identify whether the action is enhancing swimming performance, or potentially harmful. The use of wearable sensors, and in particular inertial sensors, is an emerging field in sports monitoring and a promising tool for swimming assessment. This paper describes the scaling of wearable sensor technology from single device/single user to multiple devices/ multiple users together with a framework that allows near real time data analysis as well as post session and multi session. Results demonstrate the usefulness and feasibility for such devices in the preparation of athletes. The developed system demonstrates how analysis will facilitate the primary goals of developing athlete performance to be realised, both through poolside interventions and long term developmental planning.

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# 1. Introduction

Athlete and clinical testing for performance analysis and enhancement has traditionally been performed in the laboratory where the required instrumentation is available and environmental conditions can be easily controlled. In this environment physiological characteristics of athletes such as strength, co-ordination and aerobic capacity can be assessed. In general, laboratory studies have limitations. Firstly they do not reproduce the usual training nor competitive environment. This is particularly true for the aquatic environment. Secondly laboratory-based assessment is generally based on physiology and less suited for biomechanical measures. For the sport of swimming, in-pool analysis is generally only available at high performance facilities and usually includes video analysis and some automated timing methods. Together with hand counted data, post session analysis of video is used to generate comprehensive performance measures.

## 1.1. Swimming biomechanics

Commonly used assessment techniques can be separated into three broad areas: performance, biomechanics and physiology although there is considerable overlap between them. Performance monitoring contains measurable movements of the swimmer during the monitoring period and typically times related to their movement such as splits and lap times. Biomechanical monitoring, a detailed part of performance analysis, uses direct and indirect measurement methods to quantify the movement of the swimmer, often to map them to theoretical models and norms. Physiological investigations mainly look at the energy systems of the athlete during training, competition and recovery.

By and large the assessment process is labour intensive process. Many measures such as stroke phase, rates, counts, and lap times are manually recorded or extracted from video data through post event coding. Manual processes are dependent on high staffing levels and thus are generally unavailable for routine training activities or remote areas. Recent research in the field has identified new measures such as the coordination of key body [1, 2], these new measures are challenging to acquire with traditional methods. Understanding these movements can identify whether the action is enhancing swimming performance [3, 4], or is potentially harmful [5].

Although swimming has the principal component of motion in a single direction, information contained in the other axes of movement is critical in identifying stroke characteristics and performance. The use of wearable sensors, and in particular inertial sensors, is an emerging field in sports monitoring and a promising tool for swimming assessment.

## 1.2. Inertial sensors

Accelerometers measure inertial changes at the sensor location, in typically one or more axis, are millimetres in size; rate gyroscopes, a close cousin measure rotational information. Together these sensors enable complex body dynamics to be measured. It is well understood though that the determination of positional information is a difficult and complex task [6]. Instead, these sensors are often used for short-term navigation and the detection of fine movement signatures and features (such as limb movements). In the 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].

Researchers have also used accelerometers for determining physical activity and effort undertaken by subjects. These kinematic systems have been able to offer comparable results to expensive optical-based systems [9].

## 2. Experimental

The design of a complete swimming system based on the use of inertial sensors is divided into a number of logical blocks. These are the use of multiple inertial sensors for swimming biomechanics, the extension of these sensors to multi-segment monitoring (on one or more athletes), radio communications with sensors in the aquatic environment and cyber infrastructure for data collection, processing and visualisation by athletes, coaches and sports scientists.

### 2.1. Swimming sensors

A previously developed inertial sensor platform [11] has been validated to achieve better than hand timed performance data using a single sensor mounted on the sacrum (see Figure 1 for sample data) and extended to include radio functionality. Raw sensor data are preconditioned and stroke type is determined from a combination of orientation and component energy (validated across multiple athletes) contained within each of the orthogonal channels. Key feature algorithms were developed using hand-timed data and underwater video as benchmarks to detect strokes, wall push-offs, turns and lap times. These algorithms have been developed as a post processing method, but with a low CPU cost, to ease porting of to the sensor platform firmware.

Turns are identified by zero-crossing transitions in the vertical axis accelerometer (the axis perpendicular to the body) as the body undergoes rotation. Standing starts are detected by checking for an orientation change in the athlete's body from vertical to horizontal.

It is clear that, contained within the data, are features that are indicators of power and biomechanical action. When used comparatively these data sets have the potential to assess effects of fatigue, efficiency of training drills, and to describe quantitatively ideal 'elite' biomechanical characteristics.

Preliminary investigations into using this sensor mounted above the wrist and ankle has shown that it can detect entry and exit phases of arm stroke and kick movements together with indications of power phases in the swimming stroke. This is of great interest to the sports science community as it is difficult information to obtain otherwise.
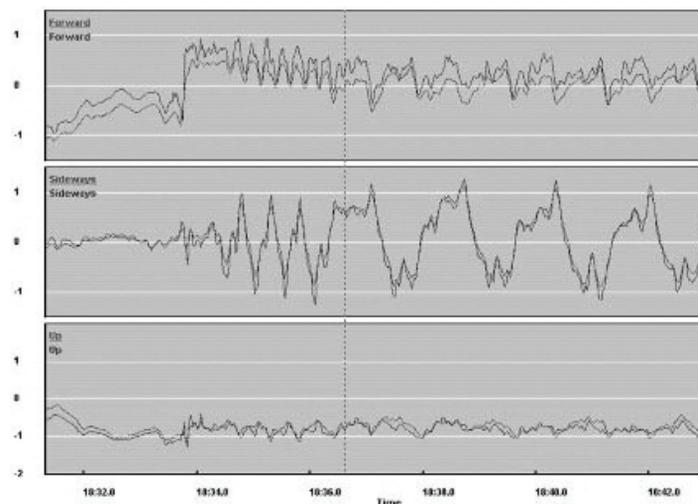


Fig. 1. Sample inertial sensor data for swimmer showing tri-axial accelerometer data obtained from wall push off, underwater swimming and four freestyle strokes.

### 2.2. Multi-segment monitoring

The simultaneous monitoring of multiple body segments of a single athlete offers the opportunity to study not only the swimmers performance through well understood metrics but also to examine the co-ordination of the body over time. These spatio-temporal characteristics are long sought metrics by swimming sports scientists [3-5] but have been difficult to routinely measure. Regularly collected data over seasons and even years, open up possibilities of analysis to examine short and long term trends in an athlete's development.  The effects of fatigue, progression through race cycle, changes over a season of coaching as a routine process have the potential to inform and enhance the competitiveness of the swimming community as a tool for examining injury recovery, efficacy of drills for technique improvement, effects of diet and strengthening and conditioning.

Technically the challenges of multi-segment monitoring include synchronisation of the data between units, extraction of the information and understanding the information acquired. While much of the data can be extracted through post processing of data, real time data acquisition or at the very least synchronisation is a minimum functional requirement.

### 2.3. Radio communications

The adaptation of the existing platform can transform it from a stand-alone storage device to a node of a functional or active network. Where previously data were stored and downloaded post session it can be streamed in near real time or synchronised to other devices. To adapt these platforms for multi segment recording a 2.4 GHz RF (radio frequency) transceiver module was used. A protocol for out of water synchronisation of multiple units was implemented to enable functional testing of the multi-segment monitoring system, though each platform still acts in storage mode.

Extending beyond this to an active network with near real time data communications between the sensor nodes and/or to a host system is under development. This requires the design of both a wireless network and an antenna with favorable propagation characteristics in the mixed air and aquatic environment. In general wireless communications performs poorly in water and additionally sensor networks that are deployed on mobile objects must cope with temporary data dropouts as well.

Significant attention was paid to the propagation characteristics in water. Novel adaptive antenna structures are under development to operate in the mixed air/aquatic environment [10, 12] and looks to be a promising candidate.

### 2.4. Cyber infrastructure

The current sensor platform and a newer version (under development) sample large amounts of performance data, however it is desired that video data be collected concurrently. Typically the sensor platform payload is 6 channels from accelerometer and gyroscope sensors at rates of 100 Hz with at least 12 bit resolution, video data is considerably larger. The collection, processing and timely feedback of the data to athletes and coaches is critical to making effective use of this information. Improvements in technique or skill acquisition are achieved when there is some knowledge of the results of an action. Sensor data or augmented representations of kinetic or kinematic movements can form this knowledge and form part of the athlete's error detection and correction process [13].

The proposed cyber infrastructure includes temporal synchronisation of all sensor platforms and synchronisation with video data. Frame creep and clock drift are important factors for recording as they become significant in only a few minutes. Radio synchronisation replaces synchronisation through mechanical artifact. The proposed infrastructure can be explained in five functional blocks.

1) Local nodes

These are typically the sensor platforms though can also include the video data feed, force plates and touch tape. Sensor nodes currently store real time data and are synchronised through local hosts. Synchronisation with video using mechanical artifact (clapper board) pre and post session with interpolation used to reduce the effects of frame creep.

2) Local host

The local host controls the synchronisation of the sensor platforms (nodes) though a USB connected node acting as a master and also receives the video feed as a post session file. In a real time system it acts as the central receiver of sensor nodes. The local host acts as a communication hub for client visualisation and communicates directly with the real time systems database.

3) Real time systems database

The handling, storage and retrieval of real time sensor data is a challenging aspect that must be designed carefully to allow scalability and is the subject of a concurrent investigation. Utilisation of a real time database allows historic and longitudinal of intra and inter athlete data for comparative analysis and trending. Poolside retrieval of current and historical information is important for feedback to the athlete and as a selective information feed for the coach especially if multiple swimmers are being supported. In the current investigation flat files are used with a Matlab visualisation client.

4) Data processing

Algorithms for sacral data have been previously described and extension to wrist and leg mounted sensors is under development using this system to collect concurrent video and sensor data.

5) Client visualisation

Current methods of feedback to athletes and coaches are usually summary statistics consisting of counts, split times and times over a session(s). It is time consuming to collect, especially for squad camps and not always available for immediate feedback. User playback of underwater video with freeze frame and slow motion are often used at the elite level though it is envisaged that in most cases it can be replaced with sensor data, once it is an accepted tool. Embedding algorithms in the sensor nodes will allow feedback to the athlete either as post session summary statistics, or during sessions such as a display on starting block or an auditory signal. With the development of RF in water and real time streaming of data to the local host and database, additional clients will be used by the coach can retrieve the raw or processed sensor information together with video.

A Matlab client was developed (Figure 2) to integrate multiple sensor platforms (up to 3) together with video data to provide the basic functionality required of a swimming monitoring system. This figure shows the integration of 2 sensor platforms, previously synchronised together with video data of the swimmer.
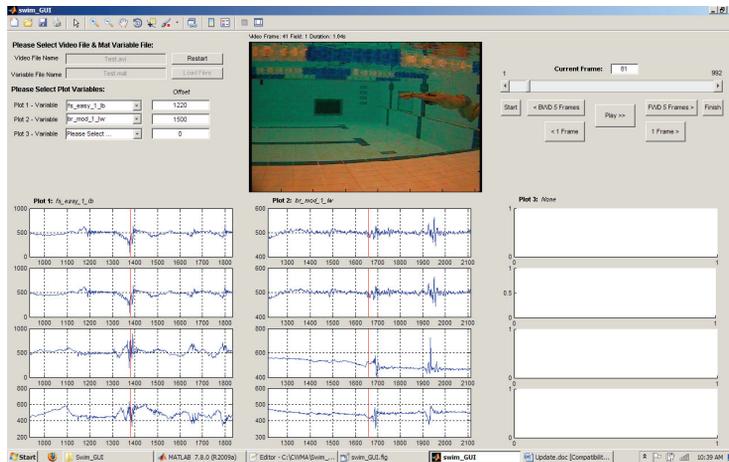
Fig. 2. Functional prototype of swimming monitoring system using hand and sacrum sensors and video feed

## 3. Conclusions and Future Work

The monitoring of swimmers and swimming performance using wearable sensors has been the subject of ongoing research. Single sensor platforms have been shown to be useful as methods of quantifying swimmer performance. This paper has described a logical extension of this method to the monitoring of multiple limb segments together with synchronized video data. A method of real time collection of the data has been demonstrated through a better understanding of RF propagation characteristics. A back end real time database has been suggested together with clients for visualization of raw and processed data by coaches and the athlete.

A functional prototype has been developed that is currently being used to conduct studies of swimming co-ordination. These studies provide important feedback to the sports science community but also to aid in the progressive implementation of the described swimming monitoring system.

### Acknowledgments

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