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## A novel, real-time biomechanical feedback system for use in rowing

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### Abstract

Biomechanical feedback in water-based rowing is traditionally presented as paper reports or video overlaid with data once a session has been completed. Research into the provision of extrinsic feedback in sport suggests that real-time feedback can lead to skill acquisition and, when appropriately applied, lead to skill retention during competition and therefore a positive performance outcome. This paper presents a novel system architecture that delivers real-time feedback using commercially available off-the-shelf components. The development of a rowing specific system to test a range of feedback strategies is presented, including fading feedback, mixing feedback modalities and varying of the frequency and timing of feedback. MoSync, a cross-platform smartphone development language, was used to write the client application while the server was written as an embedded application in C and Lua that ran on top of the OpenWrt open-source router operating system. Data was transmitted wirelessly across a Wi-Fi network. A human-centred design process was led by a group of high-performance athletes and coaches and the system was shown to deliver data to up to 10 clients simultaneously. Future research will investigate the efficacy of a variety of different feedback strategies to rowers.

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*Keywords:* Rowing; biomechanics; instrumentation; wireless networking; real-time feedback; cross-platform development tools

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### 1. Introduction

Rowing is an Olympic sport in which 1, 2, 4 or 8 athletes repeat a cyclical rowing stroke approximately 220 times over a race distance of 2000 m. Determinants of performance include the physiological capacity of the crew

to produce power as well as the biomechanical application of the available power in generating forward boat propulsion.

Extrinsic or augmented feedback mechanisms are used in sport to provide information that would otherwise not be available to the athlete (Magill, 2011). Extrinsic feedback is provided by an external source as opposed to intrinsic feedback which is received by the athlete through sensory pathways. During on-water rowing, technology limits extrinsic feedback to the visual display of number of strokes taken per minute, distance travelled and hence boat speed (e.g. SpeedCoach, Nielsen Kellerman, Boothwyn, USA). This form of feedback is termed outcome feedback or knowledge of result (Magill, 2011). The goal of the biomechanist is, however, to provide process level feedback, also known as knowledge of performance (Magill, 2011), relating to what technical improvements an individual athlete should make in order to achieve a more efficient hull motion. It should also be noted that feedback at boat level fails to differentiate the individual contributions of each athlete towards the net boat speed.

Suitable athlete level real-time feedback systems for this research were not commercially available. Systems such as Powerline (Peach Innovations, Cambridge, UK) or SmartOar (SmartOar Technologies, Breckenridge, USA) provide real-time feedback to a single user but not directly to each athlete. BioRow (Dr Valery Kleshnev, UK) and RowX Outdoor (WEBA Sport, Wien, Austria) do provide feedback to athletes however, in the case of the BioRow system, feedback can be overwhelming in its complexity while, with the WEBA Sport system, there are a range of simple interfaces offered though limited opportunity to experiment with how the feedback is delivered to the athlete. Although the use of athlete level real-time feedback is promoted (Altenburg *et al.*, 2012), the reality is that very few rowing nations currently use real-time feedback with a preference towards terminal feedback via reports and video overlaid with data.

Water-based real-time feedback has been shown to achieve skill acquisition in rowing including the reduction of hull speed variations through hull acceleration sonification (Schaffert, 2011) and the use of in-boat displays by two-oared scullers, demonstrating improved force synchronisation within 10 strokes (Mattes *et al.*, 1997). These examples, however, do not unequivocally draw the link between skill acquisition and improved race performance and this is attributed to the increased levels of attentional focus achieved when athletes are under a controlled testing environment potentially masking true levels of effectiveness (Schaffert, 2011) or attributed to the inability for an athlete to retain the learnt skill under race conditions. Additionally, feedback is either provided or not provided for a session without an ability to experiment with intra-session feedback duration or timing which may lead to a dependency on feedback (Sigrist *et al.*, 2013). There is reliance upon a single feedback modality which contradicts research that promotes the simultaneous use of multiple feedback modalities (Sigrist *et al.*, 2013) and the visual presentation of the data (Mattes *et al.*, 1997) did not undergo ergonomic trials during development.

There is, therefore, a need to develop a technical architecture for the delivery of real-time feedback in rowing that facilitates intricate coach-driven control of intra-session feedback and that follows a user-centred design approach. The design of such a system that is able to provide feedback to up to nine athletes and a coach simultaneously with the capability to 'display' information in multiple formats is presented in this paper. Best practice usage recommendations for coaches will result from the subsequent applied feedback research.

## 2. System Overview

### 2.1. System requirements

The underlying requirement of any biomechanical feedback system is to deliver a performance gain to athletes and throughout the process of development, therefore, a human-centred design methodology was followed (ISO 9241-210, 2010). This included consulting with elite coaches from the GB Rowing Team to understand their fundamental data requirements and the existing communication pathways while coaching. Workshops were run with high-performance athletes to agree the feedback concepts and the user interfaces of the initial system.

An output of the requirements capture process was a context-of-use document that detailed the system users, the tasks the users would need to perform and environmental considerations of the system, such as its use in an outdoor water-based environment. Athletes are to use the system while moving within a rowing boat and focus was therefore placed upon simplification of the feedback they received. Stroke angles, pin force and hull acceleration are examples of the biomechanical parameters that will be fed back. The feedback will be delivered directly to the athletes as well as to the coach and, importantly, those data should be semantically processed and presented in

ways that are meaningful, to give simple, but sufficiently accurate, feedback. The context-of-use also highlighted the throughput requirement of any data transport protocols adopted and the range over which the data needs to be carried. For the rowing application, the maximum data rate to 10 clients when taking 16 bit samples at 50 Hz from a data logger is 544 kbits.s<sup>-1</sup>. The required range between the boat and the client devices was set at 100 m. Consideration was given to the overall weight of equipment to be carried within the boat.

Novel requirements of the system include the wireless, simultaneous delivery of data to up to 10 users. Of particular importance is the fact that the coach will be given the ability to interact with each of the athlete displays to manipulate what feedback signals each athlete receives, as they row, based on their individual performance and requirements. This will facilitate intricate control over feedback strategies during future research while continuing to allow the coach to remain central to the delivery of elite-level rowing athletes.

Future system expansion was included as an initial requirement. As well as utilising the powerful visual display capabilities offered by tablet computers, peripherals, for example heads-up displays and headphones, might subsequently be adopted. Equally, as data may in the future come from a range of sources and not just a single rowing instrumentation system, connectivity was considered important.

2.2. System design

Data collection systems in sport consist of sensors to measure sport-specific movements or physiological parameters from the athlete, associated data storage and a local feedback pathway. Generally the stored information is used to provide terminal feedback while the local feedback is received only by the specific athlete as an audible or a visual cue. Typically the data flow is simple and does not allow the coach to monitor or customise the feedback received by the athlete in real-time. An enhanced architecture is, therefore, presented here (Figure 1).

Many sporting systems provide a real-time telemetry stream and, unless a suitable remote interface is provided by the manufacturer, it is the task of the sports technologist to route and then display this information to the athlete. Interfaces to a data producer might take a wired (e.g. RS-232, USB or Ethernet) or a wireless (e.g. Wi-Fi, ANT, Bluetooth or ZigBee) format and the interface selection will be driven by the specifics of the data producer, the required data rate, the acceptable loss of packets during communication and the physical transmission range.

Within the middleware of the proposed architecture, two roles are performed. Firstly, received data packets from any of the interfaced components are decoded to determine the intended recipient (consumer) and then routed to their desired destination. In this application, which has multiple consumers, it is possible that the same data packet will be sent to more than one consumer. The middleware also holds state information including: the current configuration of the real-time data being sensed, the currently active configurations of each consumer and any errors that have occurred during the lifetime of the session. The associated state control pathway allows any client or manager to modify the state of the middleware and therefore re-configure what data a consumer is viewing, or the bias of any feedback being received.

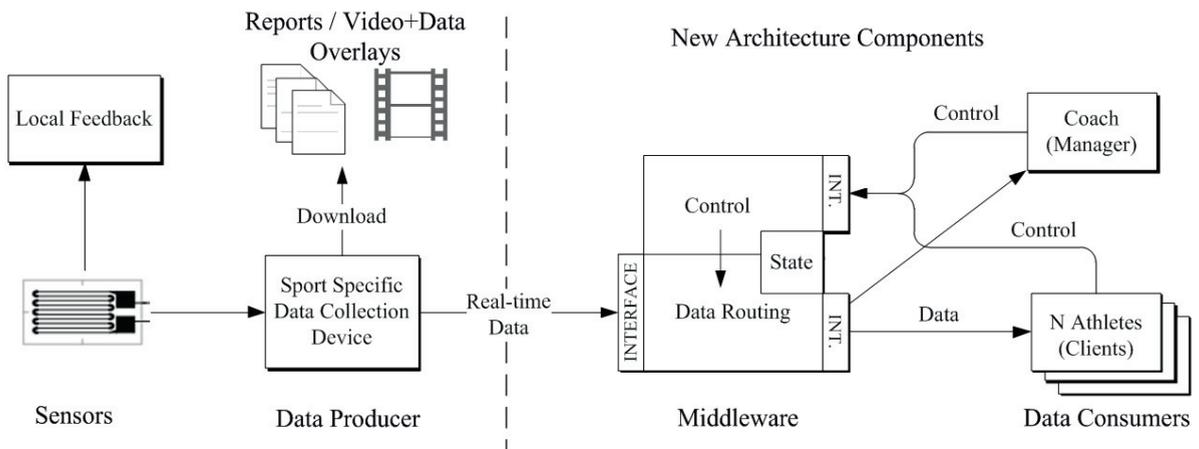


Figure 1 Generic real-time data system with integrated control loop

The athlete data consumers provide interfaces, designed and tested in consultation with the users, for displaying the live data in a format that is intended to maximise skill acquisition. The coach device will also provide data interfaces, although these will typically provide more complex data presentation since the coach is not performing simultaneous sporting movements and is therefore able to apply more cognitive processing to data interpretation.

In the system architecture, two interfaces exist between each data consumer and the middleware. The data interface is dedicated to the consumer in question and carries the relevant real-time data that originated from the data producer. The second interface is shared between all consumers and is able to read state information from the middleware and also pass control messages for configuration of their own data displays or the displays of any other consumer. It is anticipated that this ability will only be provided to the coach or manager of the training session. However, the feature opens up powerful options for the control of the feedback delivered to the athlete.

### 2.3. System Implementation

The new architecture was applied to the delivery of biomechanical real-time feedback in rowing (Figure 2). The validated Powerline rowing instrumentation system (Croker et al, 2009) was selected (Figure 3a) to produce a serial data stream. A commercial Wi-Fi router (Picostation, Ubiquiti Networks, San Jose, US) was chosen as the middleware hardware and installed with an Open-source router operating system (OpenWRT, <https://openwrt.org>). The linux utility, socat, provided serial data to a custom-written embedded C application, Peach2Net. Peach2Net routed data to consumers through sockets to each connected client device and employed named pipes to communicate with the control logic running on OpenWRT's web server software.

State in the middleware was stored using JavaScript Object Notation (JSON) files and control scripts to manage the start-up process and the control messages coming from the clients were written in Lua (<http://www.lua.org>), a scripting language with particular application in embedded systems. The rowing technician would be responsible for generating state files for each specific boat configuration and loading these for each session.

MoSync, a cross-platform development tool implemented in C++ (Ohrt and Turau, 2012 and Palmieri *et al.*, 2012), was selected to write the client application as this allowed it to be deployed to both Apple iOS and Google Android devices, the two current market-leading mobile device operating systems (Gartner, Inc., 2013). Upon investigation, the MoSync platform was found to transfer data reliably via TCP streams although it did not allow use of UDP multicasts. Threading was not available in MoSync although asynchronous behaviour was achievable through listeners and an event framework. Listeners were set-up to react to screen interaction, network activity, loss of screen focus and event timers (e.g. to periodically trigger a screen refresh).

MoSync permitted the menu system to be developed as a WebView (HTML5) or natively in C++ using the NativeUI library. Investigation showed WebViews to be the preferred route for our prototype because it was easier to predict how the same code would render on the different hardware platforms and it was also possible to utilise mobile specific, touch optimised HTML 5 libraries (jQuery Mobile, <http://jquerymobile.com>). WebViews, however, were not responsive enough to deliver the real-time interfaces nor did they provide the required design flexibility. Therefore, the data interfaces were implemented in OpenGL ES, a low-level graphical rendering library specific to mobile devices.

The client tablets were housed inside rugged casings and mounted to the foot stretchers of the boat using removable metal brackets (Figure 3b).

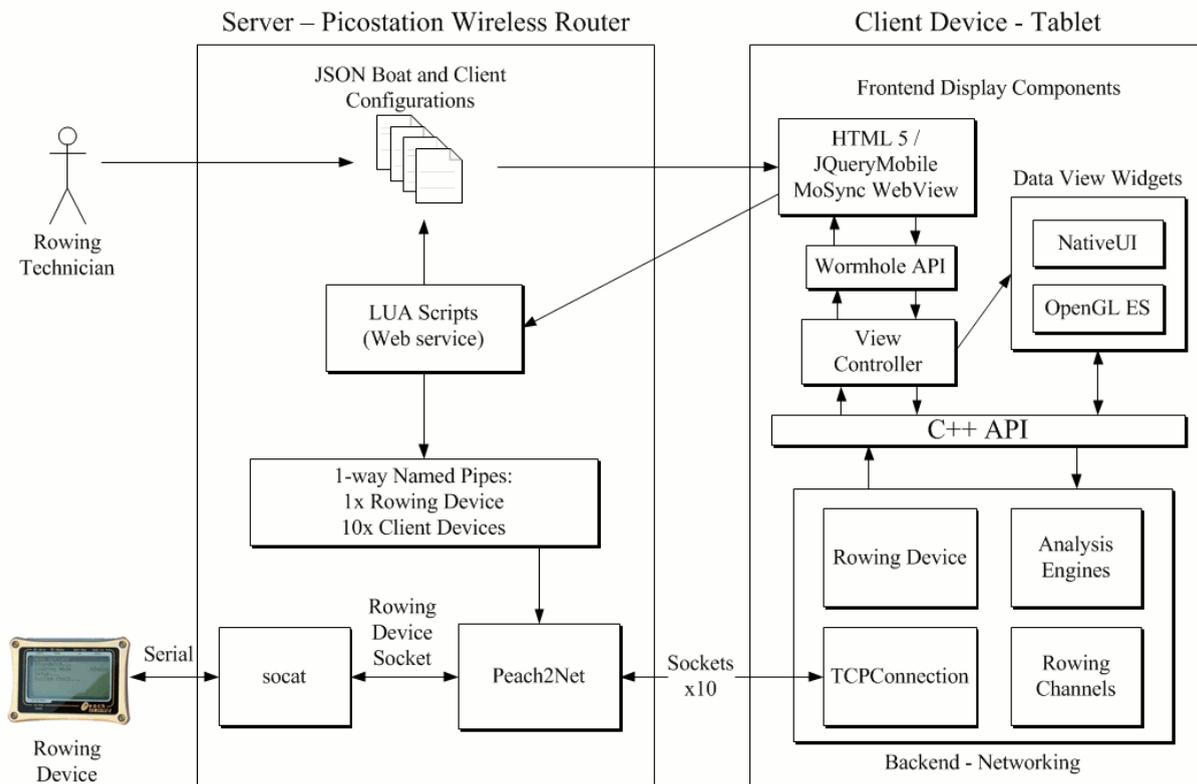


Figure 2. Software system architecture

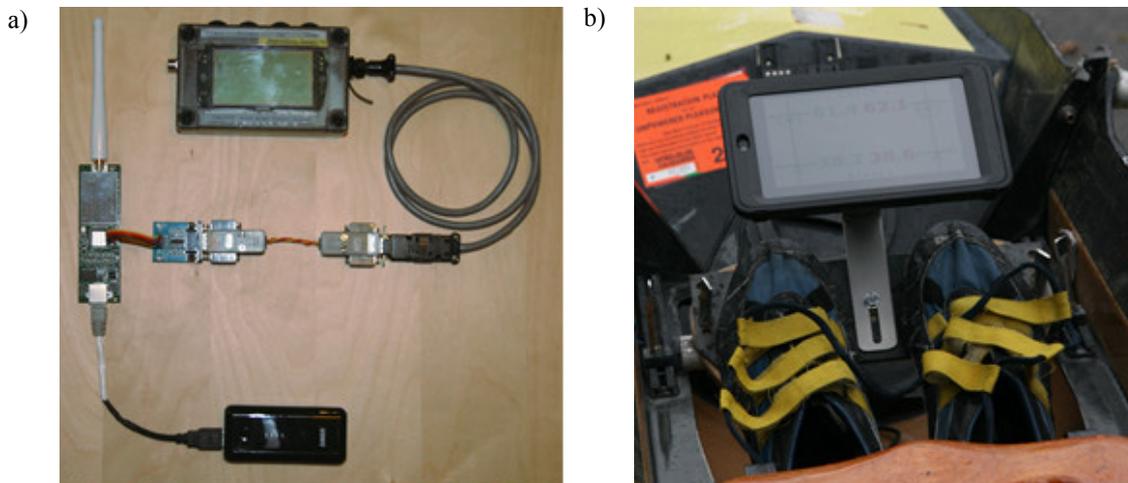


Figure 3. (a) Server components including Powerline logger, cross-over cable, TTL-RS232 level shifter, Picostation router, and battery. (b) Client display, mounted in a boat.

### 3. Discussion

This paper has presented a novel system architecture and prototype implementation for the delivery of real-time sporting telemetry to coaches and athletes and its application to rowing. The coach-driven nature of the system describes the ability of the coach to finely manipulate the feedback received by each athlete remotely and while the athlete is rowing, thereby optimising the opportunity for skill acquisition through shorter feedback cycles and feedback that is tailored to individual athlete requirements. Best practice development of the system in conjunction with its intended end-users is intended to deliver a system that is better fit-for-purpose, readily delivers a performance gain and therefore receives comprehensive user acceptance. While the coach is able to deliver a unique feedback experience to their athletes, the next stage of the research will involve investigating the efficacy of the various feedback strategies promoted across the sport-relevant literature to date.

The successful development of the system has acted as a proof-of-concept for the integration of various software and hardware technologies. Subsequent trials will capture quantitative and qualitative data related to its usability during on-water rowing. Following the iterative approach that is central to a human-centred design project, the feedback obtained will act as an input to any re-development that is deemed necessary. Once the system has been shown to be operational in the field, a series of studies will be conducted to demonstrate the use of the system to deliver skill acquisition and, with the support of the GB Rowing Team, strategic skill-based studies will be performed in an attempt to deliver performance improvements and skill retention during competition.

### 4. Conclusion

The coach-driven real-time feedback system architecture presented has been successfully applied to the sport of rowing. During the development, industry standard Wi-Fi networking has been integrated with a commercial rowing instrumentation system and modern tablet computers using a myriad of software techniques and technologies including: Embedded C, C++, Lua, JSON, OpenGL-ES, OpenWrt, MoSync, JQuery Mobile, HTML5 and Javascript. The architecture has demonstrated what can be achieved through the incorporation of a human-centred design process and with minimal development time and resource availability.

### Acknowledgements

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