A SMARTPHONE BASED SONIFICATION AND TELEMETRY PLATFORM FOR ON-WATER ROWING TRAINING

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ABSTRACT

On water rowing training greatly benefits from sonification. However, no real-time usable smartphone based platform exists for acquisition and sonification of data measured during rowing. We propose the use of a smartphone based system, coupled with an *Accrow* (BeSB) data acquisition device. The whole system is able to convey the produced sound within 100ms from the movement, thus enabling the presentation of functional real-time feedback to the rowers. The system is thought to be useful for both athletes and coaches. The sonification presented to the athletes is aimed at enhancing their perception for the movement execution with the final aim of synchronizing the crew in a uniform rhythm in order to improve the boat velocity. The sonification presented to the coaches aimed at assisting their visual observation of the boat motion in the daily training routine by listening to the sound in order to detect fluctuations that are not visible.

An empirically investigated concept of acoustic feedback that is presented in real-time during on-water rowing training sessions already exists. This paper deals with the extension of the technical hardware currently used in high performance rowing training to a smartphone based platform in order to provide the sonification to more users and to everyday club training including young and older rowers (juniors and masters).

1. INTRODUCTION

In this work we present the technical and useful advancements provided by a smartphone-based application with respect to a regular PC-based application in the field of human movement sonification in water sports.

Starting from the idea of the existing measurement and information system *Sofirow* (Sonification in rowing), that was designed as a rowing specific acoustic feedback training device as well as on the hardware-basis of the measurement and analysis system *Accrow* (both devices were developed from BeSB GmbH Sound & Vibration Engineering Berlin in cooperation with the University of Hamburg), a new convenient system was developed, that combines the two devices. The devices measure the kinematic parameters of the boat motion during rowing: boat acceleration (MEMS-acceleration sensor) and distance travelled (GPS) communicating via WiFi (WLAN). The new system is able to capture kinematic data and transfer it to a smartphone that is configured to run the task specific application, called PERSEO. The boat acceleration-time-trace is sonified (made audible) in real-time (online) by the PERSEO application on the smartphone, without the need to use an additional device, a PC, to perform the sonification.

The audio sequence produced by the smartphone can be presented on the rowing boat (for the athletes) and/or on the motor boat (for the coach). The smartphone PERSEO application maps the acceleration data acoustically as direct sound modulation (algorithmic transformation). Put in other words, the measured acceleration data defines the sound sequence. Thus, the sound sequence depends on time and is defined by the movement.

The sonification system was developed and field-tested with the German National Rowing Team [3]. With the sonification of the boat acceleration, an acoustic feedback system (*Sofirow*) was developed for high performance rowing and its effectiveness was tested with athletes from the German Rowing Association (DRV). Statistically significant improvements in the mean boat velocity as well as in different characteristics within the boat acceleration-time-trace were achieved using the sonification in on-water training. The results found demonstrate the potential of the sonification concept in principle, providing feedback about the movement execution via the sense of hearing and thus, also invisible details of the movement are subtly controlled. The sonification concept was already implemented into the technique training of elite athletes as an innovative approach to training, exhibiting a high effectiveness.

The PERSEO mobile application is an improvement of the already existing *Sofirow* PC based sonification solution. The most important advantage of using a mobile phone, compared to a PC-based solution, is its convenient, compact size, readily and inexpensively protected from water, enabling easy, daily usage of the system.

The new system makes use of an existing device called *Accrow* to perform measurements in rowing, The measuring and analysis system *Accrow* was designed for on-water training and rowing races in cooperation with BeSB GmbH Berlin Sound and Vibration and the University of Hamburg. The *Accrow* device measures boat motion data: velocity with GPS and boat acceleration with a MEMS-acceleration sensor during the rowing trip. In the previous system, the data were stored on a SD-card and transferred via WiFi (WLAN) to a notebook for online and/or off-line analysis. The offline-analysis is performed using a specific software, called *Regatta*, that performs different rowing specific routines, like load analysis, race analysis (alternatively for 2000m, 1000m or 500m rowing races), race start sequence analysis.

1.1. Related work

Tessendorf et al. [11] introduce an Inertial Measurement Unit-based Sensor Network (SN) aimed at continuously monitoring rowing technique on the water. They show the great potential offered by SN in serving as monitoring equipment in on-field training, but stop at the point of evaluating acquired data, without any mention to training. They introduce an interesting concept of rowing technique optimization loop, but give no information about how to interact with the rower.

Bresin et al. [12] improved the running technique of runners using interactive sonification. They produce sounds based on the vertical displacement of the center of mass, with the goal of making the running action more economic. Such kinds of work do confirm the idea of pervasive systems, aimed at enhancing athletes performances, in a broad range of fields.

Remote introduced by Llosa et al. [13] presents a work in which a couple of accelerometers, configured in a precise geometrical structure, enable the calculation of rotational speeds of rowing oars on water. We think that such an approach, aimed at simplifying the complexity of sensors needed to carry out measurements goes in a promising direction. However the work stops at the point of on-water tests of the system setup, without any further usage of acquired measured data.

RowingInMotion is an application for iOS based smartphones. It allows the user to use the sensors that are embedded in smartphones to measure kinematic values (speed and acceleration), and visualize them, save them to file, transmit them to another device [8]. It is however lacking the possibility to use an external device, like *Accrow*.

Thalos Rowing is an Android based Open Source application, that visualizes data coming from kinematic internal sensors of a smartphone and performs sport specific algorithms, like stroke detection, peak speed detection, and permits the data to be saved or transmitted to other Android devices [9].

By use of the *Accrow* device, a precise analysis and optimization of on-water training as well as an analysis of a rowing race profile becomes possible. Through the acquired kinematic data it is possible to calculate the essential details of the external training load (boat velocity, stroke frequency, propulsion per stroke), volume (distance travelled, number of rowing strokes) and time duration (driving time per section) [5].

With respect to the existing mobile phone based solutions we propose a system taking advantage of a dedicated embedded industrial grade sensing device coupled with an Off-The-Shelf smartphone. As the *Accrow* device has already been tested and proved to be accurate, measurements carried out using it are more scientifically relevant than others carried out using acceleration sensors, and GPS devices found on board of smartphones.

Accrow-Live [10] is an application for a Windows-based PC, that provides live visualization of the data acquired with *Accrow*. The mobile phone application, PERSEO, incorporates both functionalities of *Accrow*-Live and *Sofirow*, providing a portable real-time telemetry and sonification solution.

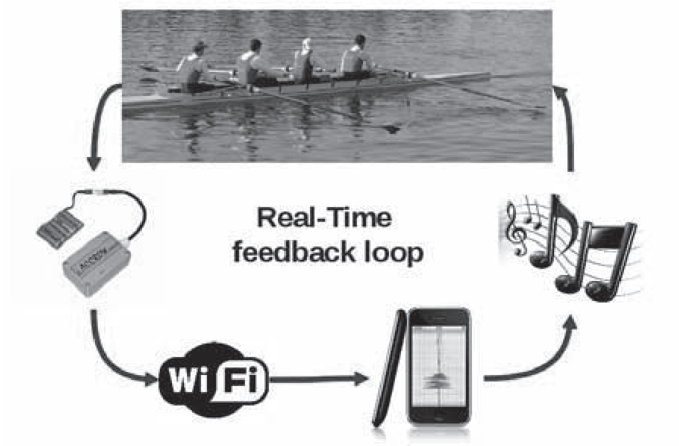


Figure 1. Overview of the complete system and its process operation.

2. SONIFICATION SCHEME

The sonification scheme that was used is rather simple: parameter-mapping, with acceleration magnitude mapped to sound pitch. The mapping was obtained implementing on iPhone all needed code, to produce the sound. We decided not to use any existing sonification software in order to explore the potentiality of the platform before starting to use something more complicated. Moreover, libraries like libpd would require to jailbreak the mobile device in order to adjust settings, which was not a viable solution in this case.

The sonification was implemented using the following formula to map acceleration values to corresponding frequencies:

$$Tone(\sigma) = A_0 \sin(2\pi\nu), \nu = 220 \cdot 2^{\lfloor \sigma \cdot 12 \rfloor / 12} \quad (1)$$

Where σ and ν represent respectively acceleration and frequency in radians/s. A_0 denotes amplitude. Consideration was given to determining A_0 in the sonification scheme, but it can be manually altered through the volume button on the smartphone.

In doing so, a 12-tone scale for the acceleration values was chosen, with values from 0 to 1. At constant conditions (0g), sound frequency = 220Hz, at an acceleration of 1g, tone frequency = 440Hz, and an acceleration of -1g (meaning deceleration) tone frequency = 110Hz. The 12-tones between 220Hz and 440Hz are thus simply obtained, without any need to involve external sonification software. Figure 2 illustrates the functional mapping between the kinematic acceleration magnitude and the frequency (i.e. tone).

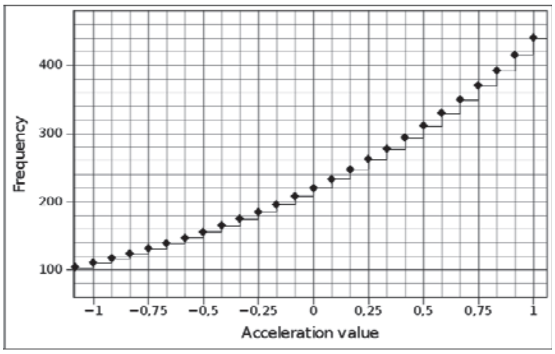


Figure 2. Discrete semi-tone scale.

To clarify the mapping, the following acceleration sequence was considered which is displayed in figure 3.

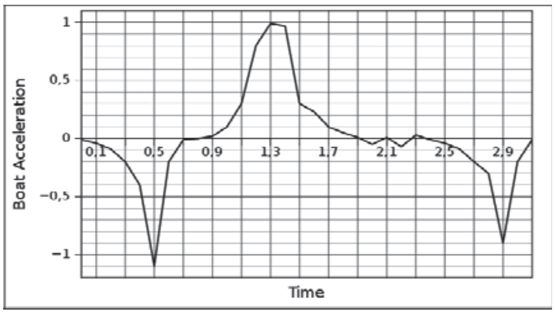
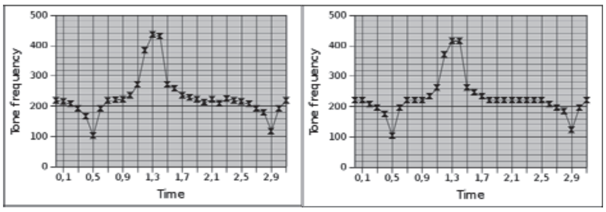


Figure 3. Boat-acceleration-time sequence.

In figure 4 a, continuous and discrete sonification schemes are displayed to illustrate how the use of discrete values obtained with equation (1) for tone data input creates a tonal scheme. The figure shows on the left (figure 4a) the continuous scheme in action, whilst on the right (figure 4b) a discretized output domain, corresponding to the discretized input domain is displayed.



a) b)

Figure 4. Continuous (4a) vs discrete (4b) sonification scheme of the boat-acceleration-time sequence.

3. MODES OF OPERATION

The application (app) on the smartphone is configured to offer a choice between two different modes of operation, both using the same sonification code, but presenting different visual information; the athlete mode presents only basic numberic data about speed, acceleration, strokes per minute; whilst the trainer mode shows two graphs, representing speed and acceleration of the boat.

The application carries out two main tasks: receiving data from the WiFi connection and processing it to present the dual visual/audio display. Received data is also saved to the internal memory of the smartphone for later post-training analysis carried out using the *Regatta* rowing specific software, and offline sonification for the purpose of exploring new sonification schemes with the same data.

To use the system, the user has to turn the device on and to start the application on the smartphone. In the screen display, preferences can be set to alter the behavior of the application, such as the possibility of switching between the sonification of the boat acceleration or its speed and the possibility of using the application in trainer or athlete mode.

4. SYSTEM SETUP

The system uses a WiFi (WLAN) connection to communicate between the *Accrow* device and the smartphone. Even though other possible options would have been available (Bluetooth, Zigbee, Proprietary RF stacks) WiFi was chosen because it is a rather stable wireless transmission standard, and moreover all smartphones incorporate WiFi transceivers.

Data between the *Accrow* device and the smartphone is transferred through a UDP stream, without any retransmission of lost packets. Retransmission is not required, as the sonification is consuming data in real-time, and packets out of sequence would generate incorrect sounds, whilst a longer wait time to correct the sequence of packets would mean the introduction of time lags, or a buffer time, that finally would translate into a longer delay between movement and sound, reducing its causality.

4.1. Mobile application software design

The design of the software running on the mobile platform was done having in mind simplicity and minimalism, in order to ease the task of modifying it in future and to have a modular and reusable code.

To tackle with a complex problem like real-time stream processing and audio generation the use of an existing design pattern was chosen: the Model View Controller (MVC) design pattern [6]. A simplified representation of basic MVC is shown in figure 5. Using the MVC pattern enables a quick modification of the application, in order to incorporate it in the future to new data sources (acting on the Model) like other sensors, and to extend the output part of the application, acting on the View.

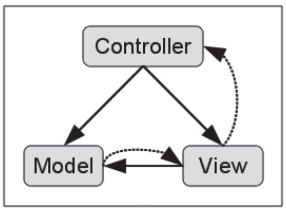


Figure 5. MVC.

Using the MVC pattern it is quite easy to deal with the different forms of visualization (graphic, or audio). We successfully used the same pattern also on an Android system on which other sensors where tested. In MVC the application is analysed into 3 parts: Model, that in a sensor application can be considered the data source (the part of the application that reads values from sensors), the Controller is managing the “intelligent” part of the application, taking care of the data read, applying some filtering where needed (low pass filter, windowed FIR filter [7]), and the View that represents the “output” of the application. The first step in the development of the application has been to implement a graphic only view, and later add an additional *audio View*.

Figure 6 gives an overview of the complete layout of the application design.

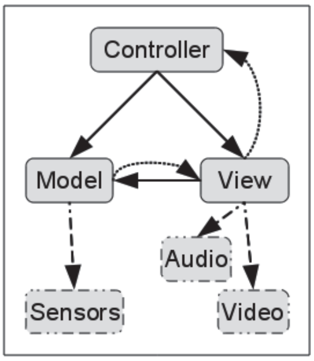


Figure 6. Design of the mobile application.

In the future, the mobile application can be easily extended, simply acquiring new signals, or carrying out signal processing to generate new signals to produce other sounds.

5. EXPERIMENTS

We first tested the system in the laboratory, to measure action-to-sound delay. The tests were repeated and the results show an average delay between 50 and 90ms that is within the 100ms-time-limit for causality of action-feedback in sonification.

Experiments with the newly developed system will be carried out in Italy and Germany in several local rowing clubs. The experiments will focus on the usability of the system. As the transmission range of the device is in the order of magnitude of tenths of meters, coaches can be in a distance of the athletes’ boat, thus providing a usable, simple and affordable mobile telemetry system.

The on-boat sonification has already been proved to be important to athletes [2]. In near future we plan to start using the device on a more regular basis, carrying out experimentation that allow to acquire more knowledge about the short and long time effects of a regular usage of the system.

6. CONCLUSIONS

The developed system consisting of an *Accrow* wireless sensing device and a mobile phone and the PERSEO application enables real-time sensing and sonification of rowing training.

In future work it could be possible to add a sonification library, like SuperCollider or PureData to the application. PureData has actually been discarded as on newer versions of iPhone (starting from version iOS 3), it seems to be no longer supported.

7. ACKNOWLEDGMENT

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8. REFERENCES

[1] http://www.accrow.de/englisch.html

[2] http://www.sofirow.de/english.html

[3] Schaffert, N. & Mattes, K. Designing an acoustic feedback system for on-water rowing training. *Int J. Comp Sci Sport*, 10 (2) 2011: 71-76.

[4] Schaffert, N., Mattes, K. & Effenberg, A.O. *Acoustic Feedback in High Performance Rowing.* In Meeusen, R., Duchateau, J., Roelands, B., Klass, M., De Geus, B., Baudry, S. & Tsolakidis, E. (Eds.). Book of Abstracts of 17th Annual Congress of the European College of Sport Science (ECSS) 04-07th July 2012, Bruges, Belgium, p.216. ISBN 978-90902686-8-2.

[5] Mattes, K. & Schaffert N. A new measuring and on water coaching device for rowing. *J. Hum. Sport Exerc*. 2010; 5(2):226-239.

[6] Gamma, E., Helm, R., Johnson, R., & Vlissides, J. *Design patterns: Abstraction and reuse of object-oriented design* (pp. 361-388). Springer Berlin Heidelberg, (2001).

[7] Avvenuti, M., A. Casella, and D. Cesarini. "Using gait symmetry to virtually align a triaxial accelerometer during running and walking."*Electronics Letters* 49.2 (2013): 120-121.

[8] RowingInMotion - http://www.rowinginmotion.com/

[9] Thalos Rowing - http://nargila.org/trac/robostroke

[10] Schaffert N., Gehret, R. & Mattes, K. Accrow-Live – Echtzeit Visualisierung von Messdaten. *Rudersport*, 4, 2011, p.22-23

[11] B. Tessendorf, F. Gravenhorst, B. Arnrich, and G. Troester. “An IMU-based Sensor Network to Continuously Monitor Rowing Technique on the Water.” *Proc. of the Seventh Internat. Conf. on Intelligent Sensors, Sensor Networks and Information Processing,* 2011, IEEE Press

[12] M. Eriksson, and R. Bresin. "Improving running mechanics by use of interactive sonification." *Proceedings of ISon (2010)*: 95-98.

[13] J. Llosa, I. Vilajosana, X. Vilajosana, N. Navarro, E. Surinach, and J. M. Marques. “REMOTE, a Wireless Sensor Network Based System to Monitor Rowing Performance”, Sensors 2009, 9: 7069-7082.