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MEDIATION: an eMbEddeD system for auditory feedback of hand-water InterAcTION while swimming

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Abstract

In swimming sport, the proper perception of moving water masses is a key factor. This paper presents an embedded system for the acquisition of values of pressure on swimmers hands and their transformation into sound. The sound, obtained using sonification, is used as an auditive representation of hand-water interactions while swimming in water. The sound obtained is used as an auditive feedback for the swimmer and as an augmented communication channel between the swimming trainer and the athlete. The developed system is self-contained, battery powered and able to work continuously for over eight hours, thus, representing a viable solution for daily usage in swimmers training. Preliminary results from in-pool experiments with both novel and experienced swimmers demonstrate the high acceptability of this technology and its promising future evolution and usage possibilities.

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Keywords: Auditory feedback; Swimming; Real-time Sonification

1. Introduction

Interactions between human beings and technology are quickly increasing, changing people's daily life. Information technology is being increasingly adopted in several sports in order to measure and possibly enhance the performance of athletes and the awareness of trainers. People can positively benefit from the interactions with technology in the training activities. The fast and widespread development of sensors, single-board computers, and other components can be fostered to design user-specific systems. During the last years an ever increasing number of sports disciplines are positively exploiting the possibilities offered by such technologies as monitoring, and off-line (post-action) / on-line (during the action) feedback. Swimming, as well as other water sports and aquatic space activities, represents intriguing activities that can be better studied thanks to technology. However, they take place in a harsh environment, in which electronic components, communication and form factors hinder the fast development that has characterized other "dry" activities. Thus, although swimming has not received many contributions in terms of on-line feedback to the swimmer, it seems to be a highly promising field of application of the techniques of sonification,

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that is the transformation of data (information) into sound. The transformation of water pressure into sound is an intuitive process, also because both phenomena are characterized by similar wave-like behaviours. A device has been developed to measure the dynamics of the interaction of the hands inside the water with the water and to present this interaction in a simple and intuitive way to the user, through sound. That interaction is measured at the level of water pressure.

Auditory and visual *feedback* are stimuli aimed at producing effects on the human nervous system [1]. Auditory stimuli are often used to help disabled people, such as blind people in their daily activities [2] and for people with attention disorders [3,4]. The use of auditory stimulation is also remarkably widespread in sports activities [5]. Functional sounds are those sounds that (can) be functional to the listener: daily life is full of those sounds, e.g., the sound of an approaching ambulance. Further unknown examples can be found in the context of sports for the blind. For example, in the goal-ball game, in which a ball is equipped with a little bell. The moving ball will lead the bell to emit sounds merely communicates the position. Skilled players are able to trace the subsequent positions and derive the direction of motion, and exploit this to catch the ball. The auditory display is a family of techniques that can be exploited to use the auditory dimension as a display, with a duality to graphical displays. With respect to the basic auditory display, sonification introduces a more formal sound definition and the process of its creation: it is a systematic and reproducible transformation of data (information) into sound.

The paper presents the MEDIATION embedded sonification system developed to provide an on-line auditory feedback to both the swimmers and their trainers. In particular, the focus covers three aspects: i) the motivation of the development of the system; ii) its technical implementation; iii) observations and preliminary results of its usage in the context of elite and novice swimmers in Italy. The rest of the paper is organized as follows: Section 2 provides an overview of the related works. Section 3 describes the proposed system. Section 4 presents tests and results. Section 5 discusses the system and the results obtained in the tests, and finally, Section 6 concludes with final remarks and future perspectives.

2. Related Works

Nowadays, measurements of the physiological state of athletes are common practices: Electromyography (EMG), skin temperature (TEMP) and Galvanic Skin Response (GSP), Heart Rate (HR) and Electroencephalogram (EEG) to better understand the athletes fatigue or Oxygen consumption. At the same time, a broad range of measurements can be performed on the physics side: acceleration, speed, force, momentum, power, impact, etc.

Electronic systems can be exploited in sportive environments to provide feedback to athletes. The performance of athletes can be positively affected by exploiting systems to measure and report feedback in the form of workout performances or to provide feedback [6–9]. In particular Havriluk [10] describes a system able to measure pressure on swimmers' hands and presents the obtained pressure data mentioning which component of flow pressure is measured. An increasingly used technique is to provide feedback to the athletes themselves rather than only providing insights about their act to their trainers. For example, in running an auditory feedback has been used to convey information about the quality of the running act, useful to reduce the oxygen consumed by the runner [8].

MEMS (Micro Electro-Mechanical Systems) acceleration sensors (used as an inertial measurement system) and a GPS device situated on a rowing boat have been used to calculate boat acceleration and average speed [11]. The same inertial sensors have been used in swimming to measure the swimmers arms stroke action [12]. Gyroscopes and accelerometers worn on arms and legs during specific exercises have been employed in order to improve athletes posture in the field of aerobics and gymnastics [13]. Accelerometers and gyroscopes have been used also in the field of golf to gain insights into shoulders torsion, golf club speed, and swing [14]. In [15], Brueckner et al., explore the design space of systems for the real-time acquisition and representation of data for motion analysis. The work presented by the authors in [16] concentrates on the intermediate level of the effects of swimming (water pressure) to provide an auditory feedback. That work did not provide any implementation of a complete system, concentrating solely on an off-line exploratory sonification work. With respect to [16], the *MEDIATION* system is a complete real-time capable sonification platform for swimming.

3. *MEDIATION* - System Description

The system has been designed to acquire pressure values from the hands moving through the water while swimming, saving and processing that information to finally deliver a feedback sound to the swimmer and the trainer. The pressure is acquired through a set a piezo-probes, also described in [17], inserted into a pair of self-designed and -sewed hand gloves. The working principle of the piezo-probes is basically similar to that of the pitot-tubes used for example in the front of airplanes to measure the speed of the plane with respect to the surrounding air. The pressure is then transmitted over 4 silicon tubes to the *MEDIATION* embedded system. The presented system was developed also in [18] and is called MEDIATION as it represents an augmented "medium", between swimmer, water, and trainer.

Embedded hardware Design. The system is composed of five elements enclosed within a waterproof box: (i) a Raspberry Pi embedded PC device; (ii) an Arduino Uno micro-controller based board; (iii) a Printed Circuit Board with four pressure sensors; (iv) a Li-ion battery; (v) an Ethernet or an optional WiFi interface. The Arduino collects the pressure values from the sensors and sends them to the Raspberry Pi over a USB connection. A specific transmission protocol called Open Sound Control (OSC) is employed/has been employed to pack the data over the USB connection. In particular, referring to Fig. 1, the sensor connected to the *palm* records palmar pressure, and the sensor connected to the *dors* records the dorsal pressure. The difference between this two pressures is called *p-diff* in the rest of the paper and represents a qualitative indication of the amount of energy transferred from the limbs to the water.

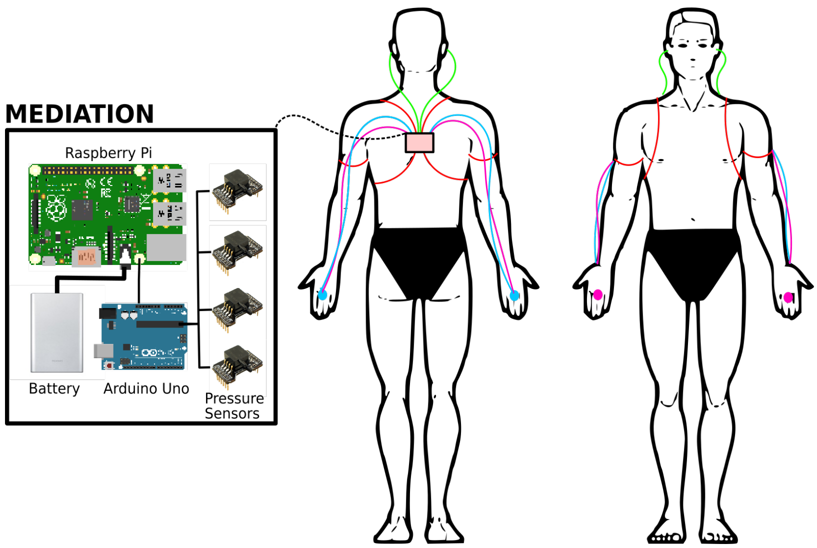

Fig. 1. Schematic view of the MEDIATION system with the tubes (in red and yellow) coming from the swimmer and the earphone lines (green) going to him.

Embedded Software Design. The Raspberry is running a program that receives the data from the USB. then processes them This program, written in PureData (PD), was developed for this specific purpose. In particular, the PD patch (program) gets the values packed with the OSC protocol from the Arduino, over a virtual serial port working over the USB connection, and processes those values, saving them in a file, and at the same time producing the auditory feedback. The produced sound is then played in real-time over waterproof earphones or headphones, for the swimmer, and over normal headphones, for the trainer. Depending on the specific exercise to be executed, the user can choose what program should be loaded and thus change the type of delivered sound (sonification mapping).

Sonification mapping(s). The sound created by a sonification system can be designed using so-called *mappings* (transformation laws of the data into the sound). Different mappings can be exploited to evidence different aspects of the actions of the athletes. In particular, the present paper presents two different approaches that have been followed:

(i) 2 pure sinusoidal tone generators, modulated in frequency based on the input data similarly to the one used in [17], bound to the palm sensors of the hands and two "fazer" oscillators, bound to the dors sensors (simple pitch mapping (1 syn & 1 fazer for each hand)); (ii) pitch mapping of the hand palmar-to-dorsal pressure difference: 2 pure sinusoidal tone generators bound respectively to left and right p-diff (1 syn for each hand).

From a technical point of view, the sound produced by the mapping of p-diff is quite different from the sound produced by the simple sonification mapping: when the hands are not moving (at any depth) and there is no water flow around them, the sound is low in volume and in frequency, while it raises when in motion. Thus, the athletes perceive different aspects of their actions and interactions with the water based on which mapping is being used.

Physical Setup. The athletes have to wear the hand gloves, the attached tubes, the earphones and a water-polo cap to prevent the earphones from slipping out during the tests. The parts of the system that are worn by the swimmer have been designed not to hinder the execution of the front crawl and the breaststroke. The equipment (gloves and tubes) is bound to the arms and on the back; the chest, belly and legs are thus left free from any tube or link.

4. Tests and Results

This Section describes the experiments and tests of the MEDIATION system that were carried out to check its efficiency, reliability, performance and acceptability. In these experiences, carried out in Italy, people specialized in different areas (Electronic and Computer Engineers, Sports Scientists and, most important, trainers and athletes) took part in the experiments. A preliminary testing has been performed in laboratory after the assembly of the system, to test whether its basic functions of acquiring, saving and transforming data into sound were working: to verify that all the parts were working the pressure sensors were connected with the tubes and pressure was applied to each tube, expecting a resulting sound output that was correctly produced. As the test has been successful investigations could continue in-field, in water.

The first test (one mapping; crawl and breaststroke) was performed mainly to check the performance of the MEDIATION system in the actual environment in which it should be used and to collect first impressions from users. Three differently skilled athletes performed the first test (AB, DC, DT) under the supervision of a trainer (SF). The athletes tried out the system swimming with different styles: (i) **Front Crawl**: the athletes and the trainer quickly noticed that "... with each stroke the sound changed from deep (when the hand was out to the water) to acuter (when the hand was immersed fully in water) ...". The audio reproduction was alternating and fairly symmetric. (ii) **Breaststroke**: The produced sound was "... giving the idea of the "reversed heart" movement performed by the hands while swimming this style".

Observations: at the end of the session the trainer observed that the sound was "... fitting the actions of the athlete during crawl and breaststroke, while for the backstroke the sound was less representative". Focusing on the front crawl actions, the athlete AB produced a higher pitch with the left hand than with the right hand (while for DT and DC the sounds were more equal). The trainer observed that this "... may be due to an abruptly increased pressure on the left palm, caused by a wrong posture of the hand, that did not interact correctly with the water, slipping away, and losing propulsion".

The second test (two sound mappings; crawl and breaststroke) compared the two different sound schemes (mappings) presented earlier: The test phase with **1. simple sonification mapping** involved again crawl and breaststroke: **Front crawl:** the sound went from grave to acute during the execution of each stroke and the feedback was alternating and symmetrical. It was firstly observed that the sound was not exactly anti-symmetrical, probably due to the asymmetrical propulsion of the arms. This would be in-line with the predominantly right-handed athletes behavior. **Breaststroke:** with respect to the observers at the side of the swimming pool, the athletes needed a little bit more time to familiarize themselves with the sound, and then confirmed the suitability of the chosen representation. The 3 athletes that swum this style had different skill levels: AB is less trained while DC and DT are more trained and used to the swimming act. In fact, with AB, only during the completion of the left stroke, an acute and fast whistling sound could be perceived, while it was not perceivable with DC and DT. Figures 2 a) and 2 b) respectively present an extract of collected data during crawl and breaststroke swimming of two elite athletes.

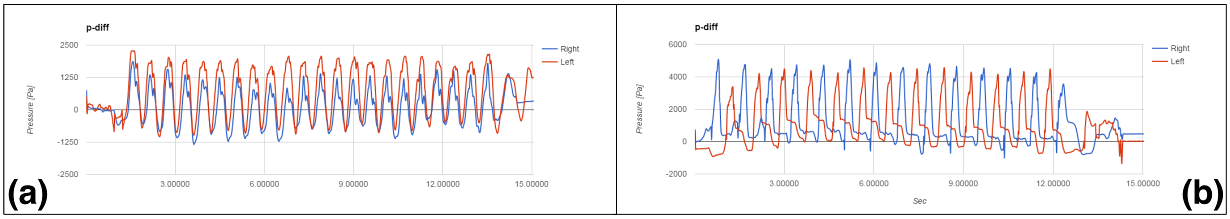

Fig. 2. Samples of the data acquired with the system during 15 seconds of (a) breaststroke, (b) crawling

During **2. pitch mapping of the hand palmar-to-dorsal pressure difference (p-diff)** test phase, the athletes, staying in shallow water, moved only the hands to understand how the designed sound works. It was possible to distinguish two different acoustic phenomena: (i) if the hand swung top-to-down with the palm facing down the sound was slightly graver and intense while moving down, while it reduced its intensity and rose in frequency while moving up; (ii) if the right hand swung from left-to-right, with the palm facing to the left the sound became more acute and intense while keeping the palm in the direction of the body and it reduced the intensity and sharpness when it moved in the opposite direction.

Observations: with both athletes CF, a novel swimmer, and GA, a more trained swimmer: (a) for front crawl, the tone was more grave and intense each time that arm came into water and it immersed in depth (similarly to the simulated top-to-down movement); whilst during the phase of recovery of the arm, the sound slowly started to lose intensity but it became acuter (due to the rotation of the arm during the stroke of front crawl that moved the hand away from the body, as in the left-to-right swinging); (b) for breaststroke the sound was deeper but less intense during the extension phase of the arms, whilst it raised in both intensity and frequency when the hands were pulled together and were at the point of maximum distance from the body, and finally, the sound tended to reduce in intensity and sharpness at the moment in which the arms came back close to the chest. Also with this kind of sound during the performance of the less trained swimmer it was possible to perceive from the sound that the movements were less coordinated, less symmetrical and had not a constant duration.

5. Discussion

This Section presents observations provided by an Italian trainer and swimming expert. The trainer represents one of the intended users of the MEDIATION system. He exposed a very positive attitude towards the system and the produced sounds. In the simple sonification mapping, the fact that the sound accentuates as the pressure increases are beneficial. In fact, taking as a reference the athletic performance of AB during the front crawl, he has been able to perceive from the sound that AB has a stronger right-side than the left-side of the body, later confirmed by visual inspection. Furthermore, the sound presents a high peak during the starting phase of the hand action underwater, providing the sensation that the hand is slipping in the water. Regarding the possibility to change the sound from a continuously changing tone to a discretized one the trainer said: "... a continuous sound is good because it provides a good idea of the motion and is immediately intuitive. But it would be interesting to test the differences between the two options." Regarding the second *p-diff* sonification mapping "... the sound reproduction allows to understand fairly well if the athlete use correctly its energy". Finally during one of the pool sessions the trainer has had the opportunity to test the system on himself: "I tried to change the motion of the hands in order to meet the projection of the sound I had in mind. I needed some time to adapt to the new experience. Finally, the sound correctly represents the physics that lies at the base of the actions that are made in water and I was very pleased with what I heard." Finally the trainer suggested to: (i) add a visual representation of the data for the trainer, with which it would be possible to observe the performance, e.g., using a tablet, in order to couple the visual and auditory indication for the trainer; (ii) save the data and play them back with the tablet; (iii) further miniaturize the system and make it more wearable.

The development of the system is an ongoing process, for which these experiments provided several new ideas and extensions. However what has been achieved until now is a fairly usable system and the sound feedback provided in real-time with a system such as the one presented in this text can be a big step forward in the training process.

6. Conclusions

This paper presented an embedded system for the real-time sound feedback generation in swimming. The particularity of our approach is twofold: first, concentrating on an *intermediate* level sonification (the pressure of the water on the hands), secondly, providing a solution able to perform the transformation of the data into sound in real-time (on-line feedback). With the adoption of this system, the expert swimmers should be enabled to easier change their behavior in swimming, towards a new and open exploration of the possibilities of interaction with the water. On the other hand, for the novice, it should become easier to understand and get insights into where the energy transfer is happening during the motion of the limbs in water. Furthermore, an intriguing question that drives this research is whether and to what extent after a long period of augmented training the athletes would be able to better imagine a given motion and its qualities only listening to its sound (as a sort of playback or feed-forward function). In future, accelerometers could be integrated into the system, in order to get further insights about the relation of fluid-dynamic aspects and kinematics of body and limbs. Furthermore another extension of the system would be the sonification of the actions of the lower limbs as an addition to the sonification of the actions of the upper limbs.

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