A REAL-TIME AUDITORY BIOFEEDBACK SYSTEM FOR SPORTS SWIMMING

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ABSTRACT

This paper introduces a novel hardware and software system to measure, process, and sonify the instantaneous hydrodynamic pressure at any surface of the human body during sports swimming. In particular, we use four sensors attached to the palmar and dorsal side of the hands to calculate the net pressure difference of piezo probes, corresponding to the net energy transferred to water due to hand actions. The information corresponds to the feel-for-water which is critical to improve the effectiveness of swimming. With our system the information is conveyed, using audio, by interactive sonifications using in-ear headphones, allowing a stereo spatialized sound representation of the interaction of both hands and water. For the first time, we hereby demonstrate in-water-experience of swimming actions using sonification. We focus on the system setup and present two parameter-mapping sonification designs that represent differently derived information and illustrate the system performance with interaction videos.

1. INTRODUCTION

Swimming is a two body interaction, namely the interaction of human body and water. Effective swimming is about how to best displace water masses using limbs under the cognitive mental control. Good swimmers are typically characterized by an enhanced level of "feel-for-water" perception. "Feel-for-water" is the ability to perceive how water flows as a consequence of pressure gradients. Indeed swimmers experience a self induced propulsion originated by their actions, and mediated by the water.

Through our system we are able to measure the hydrodynamic pressure and convey information, presented in real-time as sound, about the interaction of the hands and the water. We think that an auditory feedback could improve the training, providing a new more profound coach-athlete communication concerning the perception of water. We are currently investigating to what extent swimmers could benefit from such a system during training sessions. In fact, [3] presents an "auditory swimming coach", with the goal of integrating task analysis with subjective experience of swimmers and coaches into "psychomotor metaphors"; the skills of musicians are used to define sonic designs "in order to optimize the functional benefit", providing a workflow for designing mappings, but missing an investigation on swimmers beyond off-line playback of sound.

2. RELEVANT INFORMATION FOR OPTIMIZING SWIMMING PERFORMANCE

As stated in the introduction, sport swimming is about efficient propulsion in covering a distance in minimum time (end-effect) under limited energy reservoir conditions. A mere kinematic analysis of body motion does not explain what swimmers perceive through proprioception.

Auditory feedback of kinematics has been proposed by Schmitz et al. (2013) and was used to study the interrelation of audio and visual stimuli at a neurological level, and can be considered as an immediate effect level feedback [1]. The registration of the overall effect, the time, is typically associated with using stop watches. On the other hand, by considering flow pressure rather than kinematics, we affirm to be interested in a biofeedback of an intermediate level, because the energy transfer from limbs to water is happening exactly at this intermediate level [2]. Moreover it has been proven that the formation of flows of fluid (water) is responsible for the most relevant part of the forward locomotion of swimmers.

3. SYSTEM DESIGN

The overall system architecture is depicted in Fig. 2 To sense the static pressure component of water we use the "piezo-probe" method, that is an open hole on a wall, over which fluid can flow. To obtain electronic values we use a set of 4 differential pressure transducers, attached to the 4 tubes with an open end. The open ends are placed as "piezo-probes" between the fingers of the two hands of the swimmers as depicted in Fig. 1.

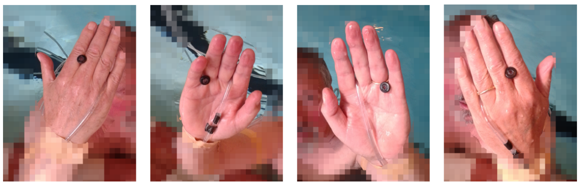

(a) Right dorsal (b) Right palmar (c) Left palmar (d) Left dorsal

Figure 1: Positioning of the probes on the two hands.

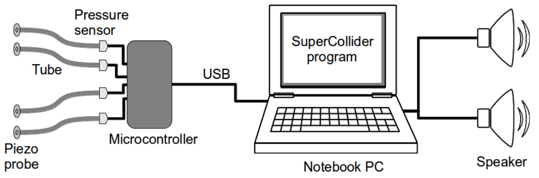


Figure 2: Scheme of the complete system: probes, tubes, transducers, microcontroller, PC, loudspeakers.

An Atmel ATMega328 microcontroller, running at 8 MHz, with a specifically self written firmware, acquires the voltage of the output of the transducers. Converted voltage values are processed and then sent to a PC for the sonification. The firmware of the microcontroller, acquires data from the A/D converter input pins at a frequency of 640 Hz. Moreover the firmware executes a simple 10:1 averaging filter, providing to the application, performing the sonification on the PC, a filtered stream of data, with a sample rate of 64 Hz.

As shown in Fig. 3 raw data quality is high, i.e. the signal-to-noise ratio is with 34 dB pretty high (due to the averaging filter implemented on the microcontroller). The data is qualitatively and numerically comparable to data reported in existing literature. In particular Fig. 3 shows a plot of 3 breast swimming cycles, for all 4 probe.

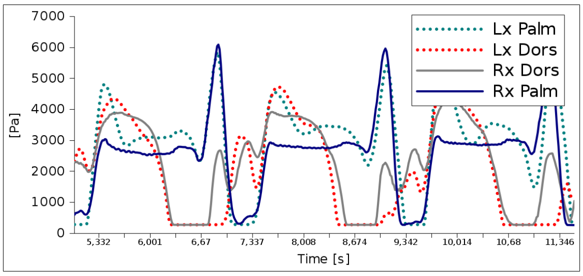


Figure 3: Plot for the 4 pressures for 3 breaststroke cycles.

4. SONIFICATION METHODS

As explained in Section 3, we collect as raw (digital) data the pressure values from 4 probes $P_{rp}(t), P_{rd}(t), P_{lp}(t), P_{ld}(t)$ (r: right hand / l: left hand, each p: palmar / d: dorsal side of the hand) at a frame rate of 64 Hz. The variables are scalar pressure values in Pascal.

The aim of the sonification is to create an awareness of the changes due to interaction of hands and water thus to provide the swimmer (and coach) with a propulsion-relevant stream of information. To omit the influence of the depth-dependent hydrostatic pressure (lowering the hand below the surface results in increasing pressure values even without any movement at all) on the flow-dependent static pressure, in order to gain information about the net energy transfer, the pressures of the palmar and dorsal are subtracted. This difference remains zero at a hand in resting water, independent of the depth in water and when in motion the value represents the flow effects. We derive our sonification designs from the two differences

$$\begin{aligned} P_r(t) &= P_{rp}(t) - P_{rd}(t) \\ P_l(t) &= P_{lp}(t) - P_{ld}(t) \end{aligned}$$

for the right and left hand, respectively.

4.1. Direct Mapping

The direct mapping sonification is a kind of baseline for sonification, using the rather most basic standard pitch-mapping to represent pressure values as continuous tones. This mapping has already been used in rowing, mapping boat's acceleration to pitch by one of the authors [5]. We apply a mapping to continuous frequencies, that is a time-analogue and value-analogue mapping, considering a linear mapping of $P_r(t)$ to freq_r, such that $P_r(t) = 0$ Pa is mapped to $\text{freq}_r = 349.2$ Hz (corresponding to MIDI note 65) and $P_r(t) = 5000$ Pa is mapped to $\text{freq}_r = 1396.9$ Hz (corresponding to MIDI note 89) for each time t. The same mapping is applied for $P_l(t)$ and freq_l.

The parameters freq_r and freq_l are used in two simultaneously running independent synthesizers presenting sound on the right and left earphone channel, respectively.

4.2. Task-specific Mapping

We developed a task specific mapping for a set of experiments dealing with the question "Can swimmers use real-time sonification to gain symmetry of pressure changes while swimming breaststroke?" Thus, as a preliminary step, we had to define symmetry of pressure changes at both hands, respectively. We actually adopted a definition of asymmetry, instead of symmetry, for the ease of later processing, as

$$\text{asym}(t) = P_r(t) - P_l(t).$$

For sonification, we use a continuous Formant filtered signal with many harmonics, controlling amplitude, frequency, spatial panning and brightness (i.e. formant bandwidth). Specifically, we mapped

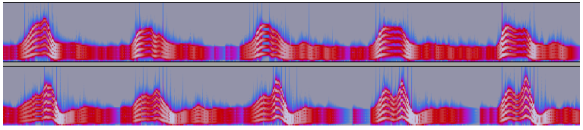
- the absolute asymmetry $|\text{asym}(t)|$ to brightness, so that higher instantaneous symmetry deviations become more salient as a spectral richer sound.
- the average signed value $\langle \text{asym}(t) \rangle$, starting from the most recent zero crossing of the $\text{asym}(t)$ function to the spatial panning, so that the spatial location is indicative to understand at what side more action is required to balance the activity.
- the average unsigned value $\langle |\text{asym}(t)| \rangle$ to the frequency of the formant synthesizer in a narrow range, so that it does not overemphasize the perceptual effect compared to the other variables. Thus, the higher the pitch gets, the more relevant the asymmetry is.
- Finally, inspired by an ecological reasoning, we mapped the absolute immediate pressure value $|P_r(t) + P_l(t)|$ to the amplitude of the sound, to obtain a sonification that fades into silence soon after there is no sustained activity.

As we regard the sound as a "call for more action", our spatial mapping pans the sound to the side where more action (energy/pressure) should be applied.

5. INTERACTION EXAMPLES

In this section, we present audio snippets (made available on our website[1] [4]) of two different test persons (M, T), both swimming a breaststroke gliding variant, while listening to the two presented mappings (S1 = direct mapping, and S2 = task-specific mapping).

(a) spectrogram for subject M, (S1: direct mapping)



(b) spectrogram for subject T, (S1: direct mapping)

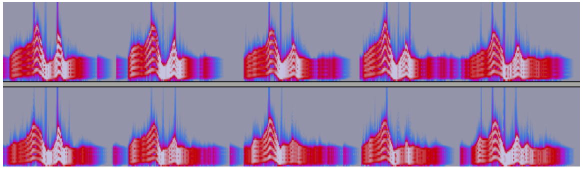
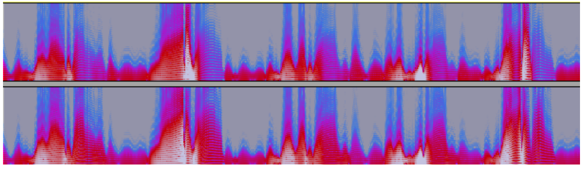


Figure 4: Comparing sonifications for two different swimmers using the direct sonification.

Comparing spectrogram of M and T sonifications with the direct mapping (see Fig. 4), we notice that subject M tends to anticipate actions on the left side with respect to the right hand. On the other hand we notice that for subject T the sound presents two peaks per cycle, possibly representing a strange movement, causing an interruption of the water flow and a consequent pressure drop.

(a) spectrogram for subject M, (S2: task-specific mapping)



(b) spectrogram for subject T, (S2: task-specific mapping)

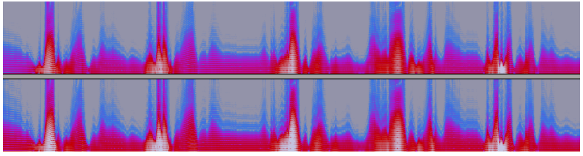


Figure 5: Comparing sonifications for two different swimmers using the task-specific sonification.

Considering the task-specific mapping (see Fig. 5), in contrast to the direct mapping, we notice that it seems to be less informative – since in fact it does not convey direct action information, but rather a complex sound representing the asymmetry. Again we can notice that the spectrogram for subject T exhibits a recurring "double-pass" hand action.

6. DISCUSSION

The two proposed mappings offer two opposite ways of using interactive sonification in human physical activities: the first is a direct and unbiased representation of the pressure changes to sound; the second, on the other hand, represents a task-specific feedback. By task-specific we mean that "decisions" were taken a-priori about the definition of asymmetry, and "intelligence" was transferred into the system in the form of the mapping. This transfer of "cognitive process" into the system is made in order to convey an already processed information of the symmetry quality of the exercise, and to guide the athlete into a predefined adjustment direction.

7. CONCLUSION

A system for the recording and real-time sonification of hydrodynamic pressure while swimming in water has been presented. Our present system is able to acquire pressure at the swimmer's hands, process it, and transform it in real-time into an auditory biofeedback. The sound is presented to swimmers using in-ear underwater earphones, while swimming. We are currently evaluating the results of a set of preliminary experiments with the goal of further understanding to which extent our system could improve or change the established way of teaching and training swimming.

8. ACKNOWLEDGMENT

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9. REFERENCES

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[1] see `http://techfak.uni-bielefeld.de/ags/ami/publications/CHU2014-ART`