Technical Survey

Development of Technology to Support Para Athletes : Tokyo Paralympics in Review

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Abstract

This paper reports on the efforts that were made to develop technology to support para swimmers as part of the High-Performance Support Project's Paralympic Research and Development Program commissioned by the Japan Sports Agency. The support initiative began from the development of training equipment for visually impaired swimmers. The development project had been ongoing since 2014 before the Rio de Janeiro Paralympics, and for the Tokyo 2020 Paralympics, swimmers with intellectual disabilities were included in the list of support targets, but in all forms of support, hearing continued to be the focus of support technology. The author, in this paper, would like to discuss the engineering support developed in Japan for para swimmers in this context.

Keywords : Paralympics, visual impairment, intellectual disability, auditory feedback

1. Introduction

The jurisdiction over para sports passed from the Ministry of Health, Labour and Welfare to the Ministry of Education, Culture, Sports, Science and Technology in 2014 on legal grounds based on the Sports Basic Law (1) of 2011. As a result, from 2014 onwards after the law came into effect, a project that had until then only supported Olympic sports was expanded to cover para sports as well. This project, called the High-Performance Support Project, included direct support for the athletes (such as mental support, nutrition management, and the analysis of videos capturing forms and videos from tournaments), the running of the on-site support center (High-Performance Support Center) during tournaments, and the development of technology to support athletes, coaches, and analysts (2). The Keio University Research Institute at SFC, where the author works, has been involved in the development of such technology since 2014. As part of the efforts to develop equipment for the Rio de Janeiro Paralympics and Tokyo Paralympics, the author was in charge of developing technology to improve the performance of visually impaired para swimmers. Later on, swimmers with intellectual disabilities were included in the list of support targets. This paper reports on the development of the given technology and presents the author's opinions about how the technological support of para sports in general should be.

2. Support for Visually Impaired Swimmers

Besides swimming, athletics, bicycle racing, blind soccer, and other sports are on the list of para sports that have a class for visually impaired athletes. In these sports, if a visually impaired athlete runs or rides with a person without a handicap, the providing of information to the athlete is accomplished by calls from the person without a handicap or by means of a sash-like connecting medium called a link. In the case of blind soccer, games are enabled by the use of a sound-producing ball and verbal instructions from the goal keepers who are not

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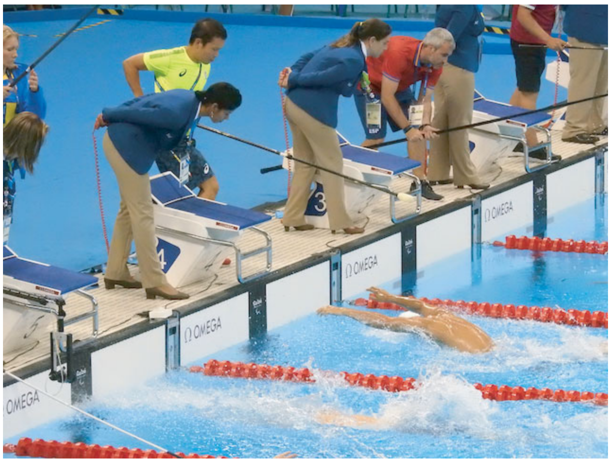


Fig. 1 Tapping during competition

handicapped. In such ways, games for visually impaired athletes are played relying solely on auditory and tactile feedback. As a matter of fact, this greatly differs from the cases of athletes who have had their lower limbs amputated playing games using a prosthetic leg that *directly replaces the lost function*, namely, the lower limb. Then, in the case of swimming, in what manner is the providing of information to each para swimmer in competition accomplished? As shown in Fig. 1, the support personnel (known as tappers) standing by at the goal point and the turn point alert the swimmer of the nearness of the wall by tapping the athlete on the back of the head or the back using a cellular porous medium or something soft attached to the end of a stick. The providing of support in this manner, called tapping, requires the skillfulness of a trained expert in that the tapper should alert the swimmer of the nearness of the wall by tapping the athlete at the right time; therefore, the task of tapping can be assigned with confidence only to the coach or staff member who performed it for the given swimmer for a long time in training. Since preventing a collision with the wall is certainly most important during training as well, tapping is the primary task for the coach, who, besides that, has to measure the time, observe the swimming, and call out start times because the swimmer cannot see the pace clock on the wall. So, compared with the case of attending to a nonhandicapped swimmer, the coach has to do much more. In the case of a single coach attending to a single swimmer, if the swimmer swims 3,000 meters during a training session, then the coach has to travel the same distance of 3,000 meters ahead of the athlete along the poolside. Therefore, as devices to assure the safety of para swimmers and help them improve performance, the author and the team undertook the development of three pieces of technology that would support para swimmers and their coaches during training through the full use of auditory feedback: *auditory pace clock*, *swimmer approach detector,* and *wireless bone conduction speaker goggles*. They will be described one by one in the following sections.

3. Auditory Pace Clock

Competitive swimmers spend much of their training time doing interval training, but visually impaired swimmers cannot determine start times by looking at a pace clock on the wall, so they must rely on verbal start instructions from the coach. However, with so much attention given to tapping, the coach, during interval training, is often prone to forget calling out the next start time. Similarly, because of the inability to check the time on the pace clock, the time up to finishing the swim must be measured by the coach using a stopwatch and told to the swimmer. To resolve such inconveniences, we developed an auditory pace clock for visually impaired swimmers (Fig. 2)[3],[4]. In this development project, the author, formerly a competitive swimmer and coach, and Tetsuro Tanigawa, project assistant professor, from the Keio University (the latter now serves as lecturer at Osaka International University) undertook the necessary specification design and functional design, while Makoto Kobayashi, associate professor at Tsukuba University of Technology, served as development supervisor.

The auditory pace clock main unit is a cluster of parametric speakers. It is adjusted so that the frequency component equivalent of the beat produced by the interaction between ultrasounds from the speakers forming the cluster will be within the audible range for humans. Because of its extremely high directivity, it has the characteristic of making the sound hardly audible when the direction it faces is even slightly changed. Therefore, we thought that, even when a visually impaired swimmer trains with nonhandicapped swimmers in the same swimming pool, nonhandicapped swimmers in other lanes will not be disturbed if the unit is directed toward the lane used by the visually impaired swimmer.

Taking advantage of this characteristic, we implemented the necessary hardware and software to realize the following three functions: (1) calling out start times

(a) Speaker side (b) Controller side (c) The speaker module and the controller module are separable

Fig. 2 Auditory pace clock appearance

according to preadjusted settings for interval training, (2) simply calling out elapsed time second by second instead of reporting the swim time, and (3) sending out from the speaker unit the voice from the coach.

The hardware of the auditory pace clock is composed of the speaker unit and the counter generator unit. The speaker unit has a voice input terminal and may also serve as a standalone speaker unit. The counter generator unit supports the calling out of start times after each interval from 45 to 90 seconds. The voice to be reproduced could be cut out from any voice recording for storage in the predefined memory area. Therefore, we recorded for this purpose the voice of a female volunteer as a voice that was found easily discernable by the swimmers. The speaker unit accepts inputs not only from the mic in terminal but also via Bluetooth connection.

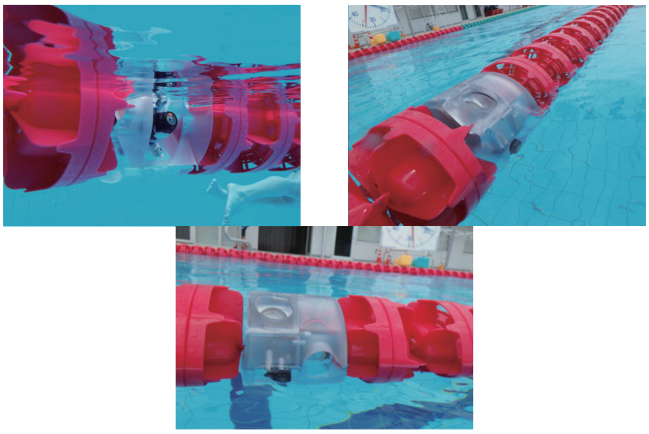
The audible pace clock is positioned using a tripod behind the starting block of the lane used by the visually impaired swimmer or placed on the starting block. Thus positioned, the audible pace clock can deliver voice to the visually impaired swimmer even when the athlete is 50 meters away at another end of the swimming pool, and the voice is not quite audible to swimmers in the neighboring lanes. So that the swimmer may start and set up the unit during training, every control button has Braille and returns a confirmatory verbal message when pressed down, telling the swimmer the function being selected. For use at poolside where AC power will not be available, the audible pace clock is powered by rechargeable batteries. These are nickel metal hydride batteries. Compared with lithium-ion batteries and lithium-polymer batteries, they are heavier, but unlike them, they are not banned from being placed in checked baggage when flying abroad for tournaments. So, we chose to use widely marketed nickel-metal hydride batteries available outside Japan as well.

4. Swimmer Approach Detector

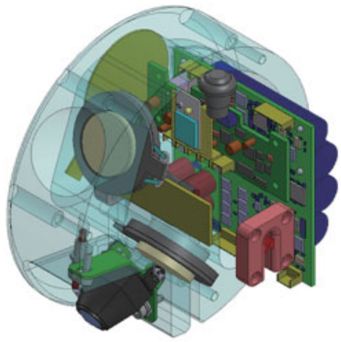
The swimmer approach detector allows visually impaired swimmers to train in a swimming pool without a supporter. That is to say, the device substitutes for tapping (Fig. 3)[(3)~(6)].

The swimmer approach detector is a cylindrical underwater camera that is 150 mm in diameter, which is the maximum allowable diameter for the lane line according to the official rules. It is mounted onto the lane line wire from above; it can be placed anywhere on the lane line. Although the camera fixed to the wire may turn as it is hit by waves, the optimal center-of-gravity design ensures that the camera angle continues to always be downward. Currently, we expect the device to be installed at the distance of five or two meters from the wall.

Traditionally, in Japan, swimmers keep to the right as they train in a lane, so the device is mounted on the lane line that is on the right side of the lane in relation to the approaching swimmer's direction of swimming. The device uses a super-wide-angle lens in the camera that looks down into the water. When a swimmer comes into the camera's field of vision from the left and passes in front of the camera approaching the wall, the device issues an alert sound from an above-water speaker and an underwater speaker. The audio data for the sound to be reproduced may be loaded onto the device from outside via Wi-Fi. The procedure performed by the device is the process of approaching object recognition



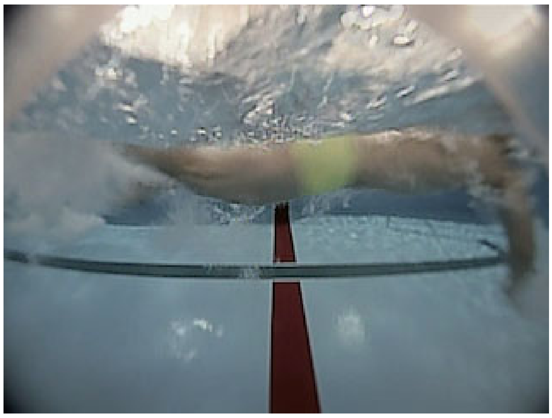
(a) Appearance



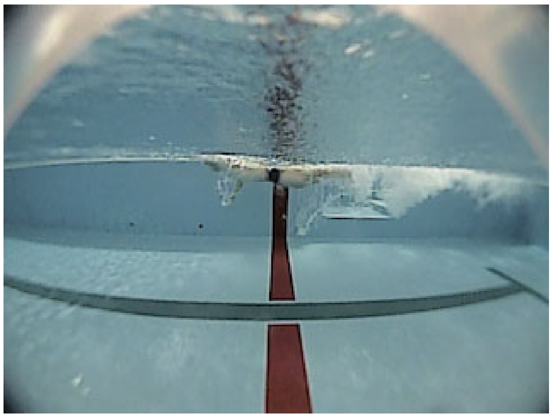
(b) Skeleton drawing

Fig. 3　Swimmer approach detector appearance and skeleton drawing

through image processing, but since the camera constantly sways with the lane line, the simple processing of background differencing technique cannot lead to the identification of the swimmer quite successfully. Moreover, light from above the surface that reflects on the pool bottom, producing changes in the luminance information, like the silhouette of the moving swimmer, also defy identification through the simple examination of background differencing. The author and the team, therefore, decided to apply different filters in multiple stages and adjusted their variables to make sure that the device issues an alarm only when the approaching figure is moving at a speed that corresponds to the speed of a swimmer in training and when this figure is moving toward the wall. The image of the swimmer in the given lane that may appear on the right side within the camera's field of vision, namely, the image of the swimmer immediately after starting off, appears only as a small figure due to the large distance from the camera ; therefore, it can be filtered out (Fig. 4), and in fact, the device is designed to ignore it. When an approaching swimmer is detected, the device issues an alert sound from an above-water speaker and an underwater speaker. Detailed functional descriptions are found in reference documents and patent specifications[(3), (4), (6)]. Using this device, visually impaired swimmers can train in a swimming pool by swimming back and forth in a lane without relying on tapping. Before the Tokyo 2020 Paralympics, considering that the basic function of the swimmer approach detector was to detect the passing of the swimmer by the device, we improved the device to support the transmission of the swimmer's passing time to the wireless bone conduction speaker goggles described in the next section so that the swimmer may hear the voice. The device allows applications to other purposes.



(a) Swimming at the near side



(b) Swimming at the far side

Fig. 4　Comparison between the image of a swimmer at the near side and the image of a swimmer at the far side

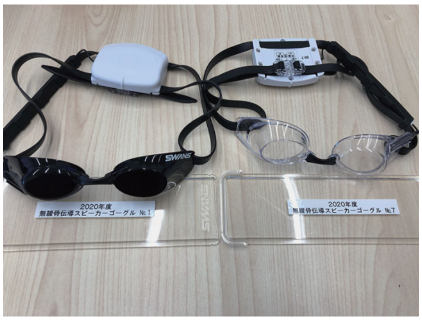
The practice of the 25 meter sprinting, for example, may be automated by placing the device at the 25-meter position.

5. Wireless Bone Conduction Speaker Goggles

The wireless bone conduction speaker goggles serve as a wireless device that transmits the coach's instructions via voice to the swimmer (Fig. 5)[(3)~(5), (7)]. The sound conduction mechanism used by the goggles is basically like this : piezoelectric elements fitted to goggle eye caps (lenses) vibrate the wearer's orbits, which are barely covered by fatty tissue, delivering sounds by bone conduction. The piezoelectric element driver circuit, the wireless communication circuit, and the power circuit are secured to the goggles' rubber band, allowing the wearing of the goggles by swimmers doing the crawl, breaststroke, or other technique and keeping the back of the head above water most of the time. Since wireless communication is used, the device, unfortunately, cannot be used by swimmers doing the backstroke because it would submerge the receiver unit.

Since the device was developed before the Rio de Janeiro 2016 Paralympics, it was greatly improved in terms of structure and function before the recent Tokyo Paralympics. While the Rio model used eye caps fabricated using a 3D printer, the newly developed goggles used eye caps formed using metal dies, which are much more durable and precisely made than the earlier ones because they were now made of polycarbonate. The way piezoelectric elements were sealed and inserted was improved as well. A module-type design for the inclusion of a piezoelectric element was chosen for the Tokyo 2020 model with a mechanism to insert the module into the eye cap. This brought the advantage of allowing the replacement of the module when a piezoelectric element fails. The wireless receiver containing an antenna attached to the goggles' rubber band was made much smaller from the earlier model through the design and implementation of a dedicated circuit board. In addition, the waterproof casing was streamlined laterally in consideration of fluid dynamics, successfully eliminating the problem of chattering vibrations that used to appear because of turbulence after starting off or after turning (See Fig. 6).

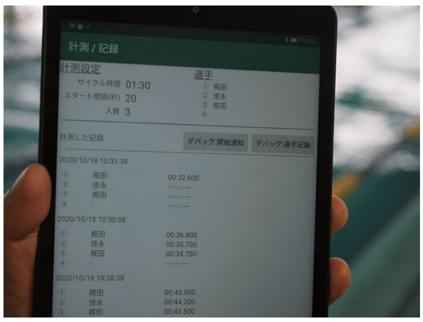
While the communication unit of the Rio model used Bluetooth Class 1 (maximum communication distance of 100 meters) to enable one-to-one communication with



(a) Main unit

(b) Worn by the swimmer

(c) Transmitter cum stopwatch



(d) Automatic sending of split and goal time to a tablet device

Fig. 5 Wireless bone conduction speaker goggles

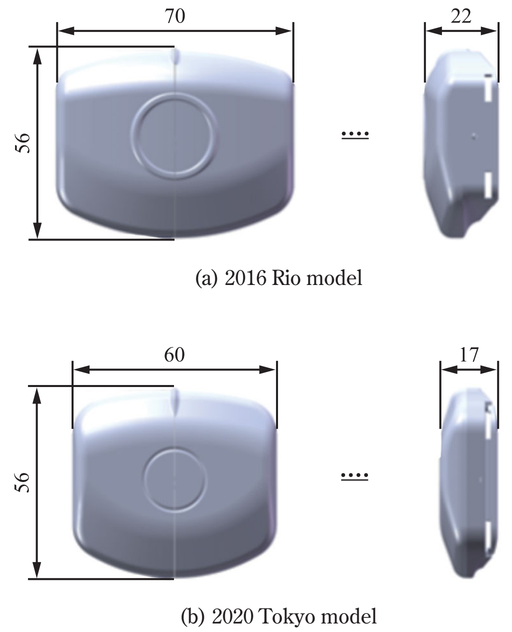


Fig. 6 Improvement to the receiver unit of the wireless bone conduction speaker goggles

the transmitter held by the coach, the transmission unit of the Tokyo model used 2.4 GHz wireless LAN (IEEE 802.11n) to enable one-to-n communication. This, however, produced the need to have a wireless LAN base station at the poolside. In the earlier model, the base unit (transmitter) held by the coach only had a microphone terminal to serve simply as a transceiver-type transmitter. In the new model, it evolved into a greatly improved unit that could also serve as a stopwatch. The coach speaks to the swimmer through a headset connected to the stopwatch-type transmitter. The swim time, namely, the time spent for completing each lap is announced to the swimmer through the goggles by mechanical voice each time the coach presses the stopwatch lap button. In this manner, the swimmer can hear the swim time through the goggles. As a coaching support feature, the swim time can be automatically transmitted to a tablet device at the same time, which may be used to display after training a list of swim times by the swimmer, and the list can be downloaded as a CSV file.

6. Conclusion

The swimmer approach detector alerts the swimmer of the approach to the wall by issuing an alert sound from an underwater or above-water speaker. During the development of the swimmer approach detector, we came across a mystery around the swimmer's auditory experience underwater. Since swimmers sometimes reported that it was difficult to hear even when sound of very large magnitude was issued from an above-water and underwater speaker, the author and the team took measurements using a hydrophone to find out what exactly were the sounds that swimmers heard underwater. As a result, we found that, even during normal training, the sound produced by the swimmer was very loud. Even though many of us who were involved in the development, were, like myself, formerly or presently competitive swimmers, we never felt as we swam that we were training in such a noisy environment. Since we even believed that we swam in silence, this fact that we came across was shocking. In response, we redesigned the device to produce the alert sound at a frequency range of around 3 kHz where the underwater sound spectrum left a small gap.

Acoustic engineering on land, that is to say, in the atmosphere, has been the subject of study for a long time and has been applied to acoustic equipment like speakers and to building design. The study of underwater acoustics, with a particular focus on ultrasonic waves, is also an established field. However, we found that the accumulation of knowledge about the perception of sounds by humans at or near the water surface is almost nonexistent in the world. Although the sense of hearing demonstrated by professional divers while engaged in underwater tasks has been addressed in earlier studies, we do not think that findings from them can directly apply because, in that case, sounds come through bone conduction.

Similarly, during the development of wireless bone conduction speaker goggles, we encountered cases of swimmers not being able to read quite well some verbal instructions from the coach. Typically, when the coach gives a swimming instruction through the wireless bone conduction speaker goggles that is utterly unimagined or unexpected by the swimmer, it often happens that the swimmer does not understand: "What did the coach say?" This is similar to what may happen in daily conversations when the context is not understood. So, we had to acknowledge that, in practice, it was important to have a preliminary agreement between the swimmer and the coach as to the types of instructions that could be given. These facts suggest that, even after the developers have become convinced of their success in developing instruments and devices, communication depends on tacit subconscious understanding that underlies our daily behaviors. The fact that swimmers, while training in a swimming pool producing noise comparable to a roar in terms of sound pressure level, are almost unaware of the noise, suggests the working of physiological specificity around the masking of the sounds produced by the athlete, but study of the swimmer's auditory experience underwater has just begun.

While engaged in the research and development of technology to support para athletes, we had opportunities to have glimpses into advanced information processing that people accomplish subconsciously in daily activities, which we find rewarding because they provided us with a number of delightful discoveries that make the science interesting to researchers.

Finally, the author would like to acknowledge that the development of the auditory feedback devices mentioned in this paper was helped by the cooperation of para swimmers in all aspects, including the acquiring of basic data and the performance evaluation of prototypes. We thank the swimmers and coaches who dedicatedly helped the research and development of technology for para athletes.

The para sport support technology, in fact, is mostly dedicated to seeking ways to improve the performance of athletes while establishing their assurance and safety ; therefore, it may in future become part of the core technology to support sports activities and the lives of persons with disabilities or handicaps. The strengthening of the conviction in this is experienced by the author as another reward from the project. The author is thankful for having had opportunities for such rewarding experiences.

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