Goby: A Wearable Swimming Aid for Blind Athletes

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ABSTRACT
We introduce Goby, a swimming aid that provides audio feedback for blind and visually impaired athletes. Goby's activity tracker is worn on the thigh and uses a downward-facing camera to track the swimmer's position in the pool. Goby detects when the user is swimming outside the lane or approaching a wall, and warns the user via an audio notification. In this paper, we introduce the Goby prototype and share formative feedback about the prototype from blind and sighted swimmers.

Keywords
Accessibility; blindness; wearable computing; fitness

1. INTRODUCTION
Swimming is a whole-body, aerobic exercise with low impact on the body. Most people, regardless of their age or physical fitness, can include swimming as part of their exercise plan. However, swimming in a shared pool can be challenging for blind and visually impaired people, as it can be difficult to track one's position in the pool. Without the ability to accurately track their location, an untrained swimmer may veer outside their lane, bump into the pool wall, or even collide with another swimmer.

Currently, some blind swimmers address this challenge by swimming with a specially trained aide known as a "tapper," who can warn the swimmer about nearby swimmers or other obstacles [2]. The tapper observes the swimmer from outside the pool, and taps the swimmer with a long foam pole when it is time to change direction. While a human tapper may enable someone to swim effectively, the need for any sighted aide can place an undue burden on the athlete, who must recruit and coordinate with that aide whenever they wish to exercise [4].

In this work, we explore how a wearable device can be used to track a swimmer's location in the pool and provide feedback about the swimmer's position relative to the swim lane or other obstacles. We introduce Goby, a wearable device that tracks a swimmer using computer vision and provides feedback via audio cues. Goby's design is based on iterative prototyping with trained swimmers, and is intended to balance accurate tracking with comfortable use. In this paper, we document Goby's development, describe the current prototype, and present feedback from a preliminary evaluation of the prototype. Based on our preliminary research, we believe that a wearable swim tracker may be used to support blind and visually impaired athletes while swimming independently.

ASSETS'17, Oct. 29–Nov. 1, 2017, Batlimore, MD, USA.
ACM ISBN 978-1-4503-4926-0/17/10.
DOI: http://dx.doi.org/10.1145/ 3132525.3134822

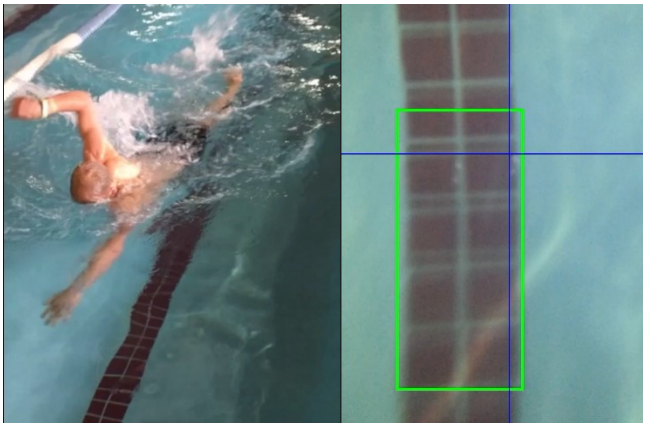

Figure 1: Goby is a wearable device that provides audio feedback for swimmers. Left: A swimmer wears the Goby prototype in the pool. Right: Goby's wearable camera identifies and tracks a lane marker at the bottom of the pool.

2. RELATED WORK
Assistive technologies can support blind and visually impaired athletes by providing information about their position or form. For example, Folmer [1] introduced an aerial-robot-based guide for runners, in which the runner could track the sound of the robot's rotors to follow a designated running path. Eyes-Free Yoga [3] used a depth-sensing camera to track a user's form, and provided audio prompts to correct the user's posture. As illustrated by these examples, a common challenge in providing access to fitness activities is balancing tracking accuracy with the obtrusiveness of the technology. For example, the eyes-free yoga system requires a depth-sensing camera, which limits its portability and prevents outdoor use. In this work, we explore the use of wearable activity trackers, which may be used in a wide variety of situations.

Relatively little research has addressed the accessibility of swimming for blind and visually impaired people. One prior attempt to support accessible swimming was Aqualert II, a device that was placed on a cable above a pool and projected a continuous spray of water down onto the swim lane [5]. While blind swimmers found Aqualert useful, it required significant effort to install. In contrast, our work leverages a wearable form factor to provide swimmers with feedback even in uninstrumented pools.

3. ITERATIVE DESIGN PROCESS
While developing our wearable swimming aid, we explored a variety of sensing methods and form factors. To sense the swimmer's position, we tested cameras, accelerometers, and ultrasonic sensors. Each sensing approach offered some trade-offs in comparison to other approaches. For example, we found that ultrasonic sensors were accurate even in turbulent water, but were less accurate than optical sensors at short ranges.

We also tested several different form factors and body locations, each of which also offered trade-offs. For example, a wrist-worn device may be more comfortable than a device worn on the thigh, but may be less accurate in tracking the user's position while swimming. Our current prototype, described here, attempts to balance tracking accuracy and comfort. We also discuss opportunities for improving this system in the future.

4. GOBY

Goby is a wearable swim tracker that is worn on the swimmer's thigh (Figure 1). Goby tracks the swimmer's position using computer vision, and provides audio feedback via a set of waterproof Bluetooth earphones.

The current Goby prototype is based on a Raspberry Pi 2 board, paired with a 1080p USB webcam and a 6000-mAh rechargeable battery pack. The components of the prototype are bound together using elastic bands, and the assembly is sealed in a waterproof plastic bag. In total, the prototype cost about $100 USD.

Goby is worn on the swimmer's thigh, and is attached to the body via a Velcro strap. During our preliminary testing, we found that placing Goby on the thigh provided the camera with a consistent view of the bottom of the pool while minimizing discomfort. The Goby prototype can easily be adapted to fit swimmers of different ages and sizes. The battery pack enables Goby to be used for several hours between charges.

A major goal of this project is to track a swimmer's location using a wearable device alone, without requiring the pool itself to be instrumented. Goby uses computer vision to track the lane markers painted on the bottom of the pool. Goby's software is implemented as a custom Python application and uses the OpenCV library. Goby tracks the lane marker at a rate of 30 frames per second. For each frame, Goby identifies the major contours in the frame, which should correspond to the lane marker at the bottom of the pool. By comparing the orientation of the lane marker to the swimmer's position, Goby can identify whether the swimmer is following a straight path or deviating from that path (Figure 1). Goby also identifies the wider T-shape that is present at the end of the lane marker, and can thus determine when the swimmer has reached the end of the lane. While this system has only been tested in a small number of pools, we are optimistic that this approach can be used across a variety of pool sizes and marker designs.

Goby notifies the user of their position via the paired Bluetooth earphones. Goby speaks the messages "swim left" and "swim right" if the swimmer veers off track, and says "wall" as the swimmer reaches the end of the lane. These messages are repeated every three seconds until the swimmer adjusts their trajectory. If the swimmer is on the correct path, Goby speaks the message "on track" every ten seconds.

5. PRELIMINARY DESIGN FEEDBACK

To gain feedback about Goby's premise, form factor, and feedback methods, we presented Goby at a design expo at our university. Because we could not easily demonstrate Goby in an actual swimming pool, we created an artificial pool marker on the floor using colored tape. Guests at the design expo were able to test the prototype by attaching the sensor to their leg, donning the headphones, and walking across the marker. We also showed a video of the Goby prototype being worn in a swimming pool. We asked each participant to provide feedback about their experience.

During this event, approximately thirty individuals tested the Goby prototype, including two blind individuals and one individual with low vision. Overall, our informants were enthusiastic about the prototype, and wished to try it out in an actual pool. Informants offered several suggestions for improving Goby's feedback: some found the repeated speech instructions to be distracting, and suggested replacing the speech feedback with non-speech tones. Others suggested changing the intensity of the sounds to indicate how far off-course the swimmer had drifted or how close they were to the wall.

6. LIMITATIONS AND FUTURE WORK

While our research team has tested Goby in several underwater settings, including a public pool, we have not yet tested the prototype with blind swimmers. Evaluating Goby with blind swimmers will provide us with valuable insights about the hardware form factor, tracking methods, and feedback modes.

A major limitation of the current prototype is that its tracking method relies upon the presence of easily legible lane markers. Thus, Goby currently cannot be used in open water, in situations in which the lane markers are not visible (e.g., in dim lighting or cloudy water), or with lane markers that look significantly different than the markers we have tested with. These issues may be addressed by improving Goby's visual sensing capabilities, such as by adding a light source to the camera, or by combining Goby's visual tracking with other sensing methods, such as an ultrasonic sensor. Alternately, users could carry a set of temporary markers that could be used in unmarked pools or even in open water.

A second limitation is that Goby must be worn on the thigh, which some swimmers might find uncomfortable, and which may be incompatible with some swimming styles, such as the backstroke. In the future, Goby could be extended to support different swimming styles and body placements.

Finally, we have identified several opportunities for improving Goby's tracking capabilities and feedback modes. In addition to identifying obstacles, future versions of Goby could also track a swimmer's speed, distance traveled, or calories burned. Goby could also be extended to provide haptic feedback, which might be preferable for some users, such as deaf-blind swimmers or those who listen to music while swimming.

7. ACKNOWLEDGMENTS

We thank Derek Reimer, Bill Casson, and Floyd Mueller for their helpful feedback. We also thank the Fort Collins Club for the use of their pool facilities.

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