Breaststroke 2 on a watch

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Abstract
BreastStroke[1] addresses recreational swimmers who want to monitor and improve their performance. The app reconstructs user breaststroke swimming with watch-based sensors. Users are presented with aggregated data of their HealthKit samples: mean durations of strokes, rows and glides; best speedup values and palm turns. Samples are transmitted to the connected iPhone for inspection.
The main purpose of the article is to explain the app to its users, with some additional information for other readers. The app environment on iPhone and Apple watch with sensors (Inertial Measurement Units --IMUs--) and useful APIs (Application Programming Interfaces) is characterized. A watch-compatible model of breaststroke swimming follows. The implementation report explains the mechanism that derives the key observational values using sensor input and breaststroke model. Users control the data uptake on the water-resistant watch interface. On the iPhone interface they find their results.
As to the experience of the author, the app results are good enough for supporting recreational and occasional breaststroke swimmers. For competitive swimmers, one might develop more sophisticated versions.

Keywords: breaststroke; swimming style; inertial measurement unit; sensor; smart watch; smartphone; user interface; IOS; WatchOS

1. Introduction

The BreastStroke app was motivated by the observation of recreational swimmers. It was easy to see that a bit of monitoring might guide them to improve their style. The watch on my wrist might do the job -- on their arms, too. Linking to some web site that explains in detail how good breaststroke looks like –- no problem. The watch sits on the wrist of the user in the pool. The phone rests outside, let's say in the user's backpack. It stores a collection of swimming samples and displays them for inspection and handling. Picking a popular swimming style like breaststroke -- a reasonable choice. Thus a watch-and-phone app for normal casual swimmers owning a phone and a watch emerged in my mind.

This article explains the BreastStroke app sketched above. First and foremost it addresses users of the app. To them, a paper can explain more in detail how the app works than the user instruction on the app does. Other watch owners might be intrigued by a paper about a watch app and possibly decide to download the app after looking at the paper.

This article roughly adopts a scientific paper format, but it addresses recreational app users. Therefore it may disappoint scientists. Watch-using swimmers can inspect one of the scientific papers referenced below to envisage the gap between a regular scientific paper and this user-oriented app description. Most of them would not invest the effort to work their way through a referenced scientific paper. Scientists are invited to accept a popularized description of the BreastStroke app. It matches with a reduced technical apparatus for monitoring swimmers -- a watch and a phone -- and it focuses on the self-control of the swimmer.

The BreastStroke app does not claim any validity beyond recording and presenting the watch sensor data measured on the swimmer. Of course, the sensors may deliver bad values sometimes. All users/test subjects' sensor values are recorded as they come in.

Whether a watch app is usable for competitive swimming and to which degree is an issue. The wrist may not be appropriate for recording how competitive swimmers perform. Where basic properties serve casual users, one may need more precision for tracking the moves of

[1] https://itunes.apple.com/de/app/breaststroke-swim-better/id1295629075?mt=8

competitive swimmers. Thus a recreational swimmer can estimate the arm pull from the max speedup, whereas for competitive swimmers one might record the whole sequence of speedup values of the move.

Astonishingly the author could set up the BreastStroke app without any notice of earlier research. Her watch and her iPhone set the technical platform. What remained to do was dressing a practical model for breaststroke to be spotted by the watch sensors, and implementing the user interface plus the technical underpinnings of the app. When the app had made it into the App Store it was reconsideration time: reading related scientific research and producing this article.

In the following, the app environment / the technical platform on Apple watch and iPhone is explored first. The watch-compatible model of breaststroke swimming follows. After that, the article turns to the implementation, explaining the processing. The user interface on watch and phone is displayed with some hints on their use. A short conclusion ends the paper.

2. The app environment / the technical platform on Apple watch and iPhone

Their home on watch and phone equips apps with services. In part they derive from the given hardware, like the sensors of the watch. Basic services are provided by the standard software of watch and phone as well. Both interact so that an app can use the following technical platform:

- Watches are safe watertight hardware. Sitting on the wrist they are convenient for swimmers.
- Watches on the wrist are well set for recording swimming styles where arms and hands do most of the activity. This fits crawling and breaststroke.
- Watches are equipped with sensors for many purposes. With their Core Motion API they serve as inertial measurement units (IMUs), tracing acceleration and attitude of the device delivering pitch, yaw and roll values.
- Watches perform a considerable amount of processing.
- The watch screen distinguishes hard and soft pressures. Thus an interface for handling in water can react on solid local presses of the user only, preventing water waves from mixing in.
- Thanks to WatchConnectivity the transfer from a watch in the pool to the related iPhone outside works ok via Bluetooth.
- Watch and phone are prepared for immediate presentation of recorded values.
- The HealthKit API supports endurance sports like swimming, in particular enabling the recording of long time intervals.

This basic configuration of watch and phone enables the design of an app that tracks swimming, in particular breaststroke and freestyle/crawling. A main condition is the use of sensors.

2.1 Sensors on the watch

The watch is prepared for many applications. For tracking all sorts of attitudes of the wearer (runner, swimmer, robot, …) the watch uses an inertial movement unit (IMU). An IMU includes sensors: accelerometers, gyrometers and magnetometers. It defines the position of the watch in its three-dimensional reference frame.

The bumblebee of fig. 1 exemplifies an object moving in the three dimensions of free space. It may

- roll around its own longitudinal axis (parameter roll)
- turn its nose horizontally to the right or to the left (parameter yaw)
- dip and lift its nose vertically (parameter pitch)

The watch behaves as an object moving in space. It sits on the wrist and looks toward the fingertips. Its attitude sensors measure the parameters illustrated by the bumblebee. Besides moving forward, backward or to one side as indicated by the object acceleration, the watch has its attitude in the reference frame, as an airplane does. The reference frame values can be recorded in any outer medium, such as air or water.

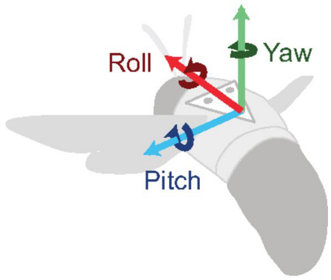

Fig. 1. A bumblebee demonstrating the three dimensions of motion in space

For breaststroke monitoring, the watch sensors can provide the following attitude values:

- The position on the wrist fits for recording the horizontal (yaw) moves of the arm, reaching out during rows, returning to the center during glides. As breaststroke is symmetrical, the values are good for both arms.
- Turns of the wrist (roll values) are observable as well. They correspond to palm movements. Adjustment of the palms is required for paddling and gliding.
- One might also track pitch values of up-and-down motion, but they are neglected here for recreational swimmers. One reason is that they are collateral in breaststroke.

Combining attitude values (here yaw and roll) with object acceleration and time values one obtains the essential moves of a breaststroke swimmer.

In swimming research, IMUs are well-known. Guignard et al (2017) and Mooney et al (2016) report on the investigation of swimmer behavior with the help of IMUs. But while the wrist position was used successfully already in Ohgi et al (2000) and remained alive as demonstrated by Bächlin et al (2011 - see fig. 2), IMUs were often distributed to different places, such as the swimmer's back, thigh and arm. This may perform better in professional environments. Ganzevles et al (2017) illustrate what an effort is invested in practical accelerometer tracking of competitive and elite swimmers.

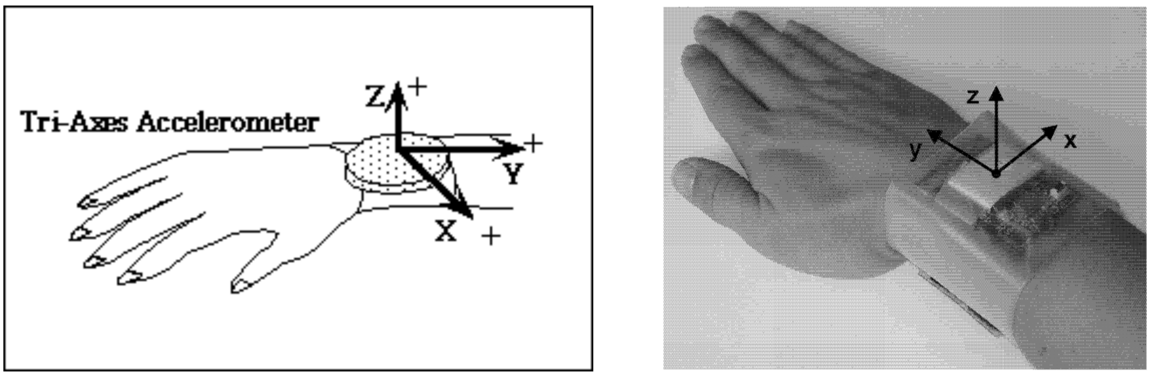

Fig. 2. IMUs on the wrist for swimming: by Ohgi et al (2000), and SwimRecorder from Bächlin et al (2011)

Some authors think that swimming mechanics is not yet fully understood. This is the experience of Nakashima & Kuwahara (2016) who interestingly developed a humanoid robot swimmer and used it for testing.

Several commercial manufacturers are offering waterproof watches for swimming[2]. Their IMU-based swimming apps tend to be quantitative so that meters and laps set the scene. See for

[2] https://www.techradar.com/news/best-swim-watch

instance a Garmin watch test[3] on the web or a review of Garmin and SwimSense by Mooney et al (2017).

The Android-based swimming apps make up for a considerable list[4]. Often the apps combine swimming with other sports, eg., triathlon. Health and fitness[5] apps are available as well.

On IOS the Training app[6] and the Health app[7] and HealthKit[8] workouts come as standard software. They serve many sports and exercises, swimming included. Customer IOS swim apps[9] tend to conform to HealthKit targets such as counting laps or meters done, but they also offer related services like communication with friends or help for finding a pool nearby. See MySwimPro[10] and Swim.com[11] as examples.

2.2 Useful system APIs (Application Programming Interfaces)

Systems do not only provide the hardware for applications, but the operating systems also support applications with APIs (Application Programming Interfaces) of prebuilt functions. So do IOS of the iPhone and WatchOS of the Apple watch. While most API functions are of general use, some of them are particularly useful for tracking swimming. For the BreastStroke app the most useful system functions are:

- Core Motion. It delivers preprocessed sensor values of the attitude reference frame and acceleration values.
- The Foundation Timer. It synchronizes the frequency of sensor scans.
- WatchConnectivity. It manages the Bluetooth communication between an iOS app and its paired watchOS app.
- HealthKit. It provides samples for long-term workout tracking with some specification for activity types such as swimming, bowling or biking.

3. An empirical breaststroke data processing model

Simple observational knowledge about breaststroke swimming tells the BreastStroke app what to look for:

- Breaststroke swimming is a sequence of strokes.
- Strokes consist of two phases, one of rowing arms, one of closing / gliding arms with concurrent leg kick.
- Both arms move in parallel, with mirror symmetry.
- Strokes are cyclic. A stroke ends in the start position of the next stroke.
- The arms move sideward. They deviate from the forward direction in a regular pattern.
- The leg kick happens during the glide move of the arms.
- The swimmer moves forward, thus setting the overall direction and producing acceleration values.

Fig. 3 illustrates the phases of a breaststroke. Legs are shown inside the circle, arms outside. The right semicircle corresponds to the rowing phase, the left one to the glide phase.

The view is simple, empirical and natural for everybody's use, but it renders only a part of the breaststroke performance:

- It does not tell what the hands of the swimmer do. The palms are supposed to turn out for paddling during the rowing phase, and to flatten or fold together when gliding.

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[3] https://www.yourswimlog.com/garmin-swim-watch-review/

[4] https://joyofandroid.com/best-swimming-coach-apps-android/

[5] https://www.androidauthority.com/best-health-apps-for-android-668268/

[6] https://support.apple.com/de-de/HT204523

[7] https://www.apple.com/ca/ios/health/

[8] https://www.wareable.com/apple/how-to-use-apple-health-iphone-fitness-app-960

[9] list at https://www.igeeksblog.com/best-iphone-ipad-swimming-apps/

[10] https://itunes.apple.com/us/app/myswimpro-personal-swim-coach/id994386450?mt=8

[11] https://itunes.apple.com/us/app/swim.com/id956030704?mt=8

- The up and down of the upper part of the body is missing. When the swimmer is rowing, the torso lifts, so that the swimmer can breathe in. During gliding, the shoulders sink into the water and the swimmer will breathe out.
- The cyclic motions remain on the spot. In reality the swimmer engenders some acceleration by the rowing of the arms and the kick of the legs. With a sequence of strokes, the swimmer advances.

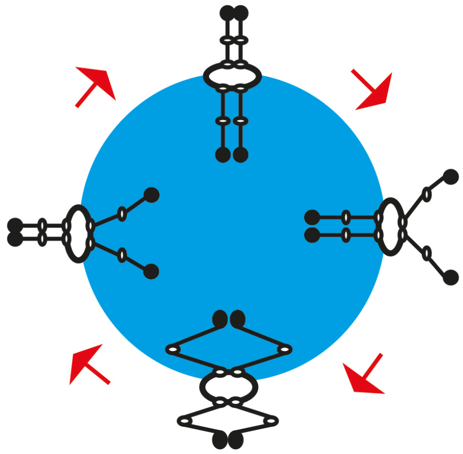

Fig. 3. The stroke cycle. The row phase is on the right side, the glide on the left. Legs are inside the blue circle, arms outside.

4. The implementation

Given the API services of IOS and WatchOS, the setting of the breaststroke tracking is as follows:

- The watch observes swimming from the left wrist. The current sampling rate is 1 / 6 second.
- As breaststroke is structured by the deviation angles of the arms, the yaw sensor values guide the tracking work. Besides yaw values, roll and acceleration values are exploited.
- A stroke starts with a row phase and ends with glide phase.
- Wider yaw angles correspond to rowing, narrower ones to gliding. With some empirical testing, the yaw range for glides has been set to 40° off the center. The margin can be easily adapted. Values outside indicate a rowing activity.
- The BreastStroke data model knows three states of swimming:
    - row phase
    - glide phase
    - unclear
- The state of the swim is unclear until the first transition to the row range (greater than 40° or smaller than -40°) has been found, so that transitions may change from unclear to row, from row to glide, and from glide to row.
- The transitions include bookkeeping operations. When a row phase ends, its values must be stored. The transition from glide to row marks the end of a stroke. At this moment, bookkeeping both for the glide and for the stroke must be done.
- Users need observation data that they can handle and make sense of. Therefore the values are aggregated. Duration / time intervals are presented as averages, speedup / acceleration with their highest values. Hand and palm turns present the respective minimal or maximal angles. One might keep more data at will.
- Speedup values are given in standard m/sec^2 units. Directions are represented as degrees of angles.

A BreastStroke sample is tracked as a sequence of sensor shots that is structured by transitions. Table 1 shows in pseudo-code style what happens when the timer triggers a sensor shot.

At the top of the pseudo-code the settings state the margins of the glide and row channel. As long as the values could not be categorized from sensor yaw measurements, they are said to be unclear. So there are three states of data: glide, row, and unclear.

There are three types of transition events:

- switching from unclear to row: finding the first row in order to start recording
- switching from row to glide range, storing best row values, preparing new glide
- switching from glide to row range, storing best glide and stroke values, prepare next stroke and row

As long as a glide or row range is persisting, its incoming data bundles are handled one after the other.

Now let the timer trigger a next bundle of yaw, roll and acceleration values:

- When recording waits for starting a new sample, the incoming yaw may either qualify as row or glide value. If it is a glide value, the time is set and nothing happens. If it is a raw value, the recording starts up, setting the first row and stroke.
- When the incoming bundle causes a swap from the row range to the glide range, the row is finished. The new glide is started. The row values are stored away.
- When the incoming bundle triggers a transition from the glide range to the row range, a glide and a stroke are finished. The best values of the glide are stored away. The finished stroke is stored. The new row and stroke is set up.
- When the next row or stroke bundle arrives after an earlier bundle of the same type, the question is whether the new bundle brings better values. If so they are noted. If not, a new stroke is counted, noting happens to the values.

5. The BreastStroke app interfaces

Users interact with an app via its user interfaces. There, transparency is a main objective. A user interface should reflect the structure of the data and a model of the app use. With a minimal set of displays and a regular design an interface is easier to handle. Some basic user instruction should be aboard.

On the BreastStroke watch, the interface mainly helps users to manage the data uptake. The watch interface has three types of screens:

- the main table
- the menu screen for steering the app
- data screens displaying strokes, rows and glides of the active sample

On the phone, user information is the main aim. The headings explain that the app is applying the HealthKit API. It belongs to the health and fitness apps on App Store.

As form follows function, the phone interface needs a larger set of screen types. On the general information layer it has

- an introduction screen
- user instruction screens
- a privacy page

For handling user swim data there is

- a sample overview table
- a stroke table
- a glides table
- a row table.

5.1 On the watch

The main table

The main watch table (see fig. 4) displays the basic data structure of the app samples: strokes consisting of rows and glides. By color changes it keeps the user oriented on the state of processing:

- In red and blue muted it is ready for a strong press that presents the menu. The top left figure renders the yaw deviation from the center the app starts with.
- In clear red and blue the buttons are activated and switch to the data screens.
- With a turquoise and yellow screen the app is recording a sample.
- In purple the app is in delivery state. As soon as the phone confirms that the data arrived, it returns to the muted red and blue state. It is ready for the next sample.

Watch data pages

The data displays on the watch (see fig. 5) present values of the active sample for a fast inspection. The buttons of the main watch screen lead to their respective detail tables. They scroll as required. Their arrow in the upper left returns to the main table. Because the data screens react at normal hits, they should be used out of the water only.

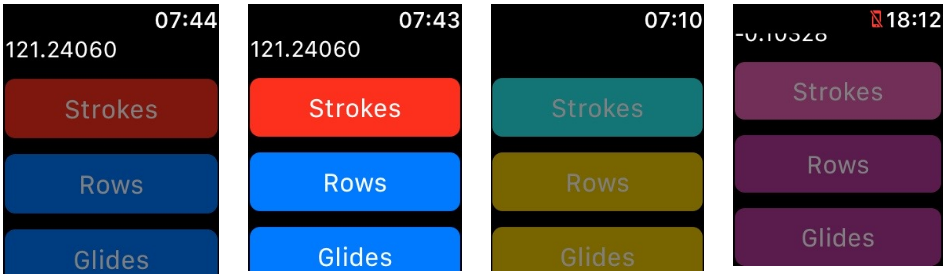

Fig. 4. Main watch screen: muted, activated, recording and delivery state

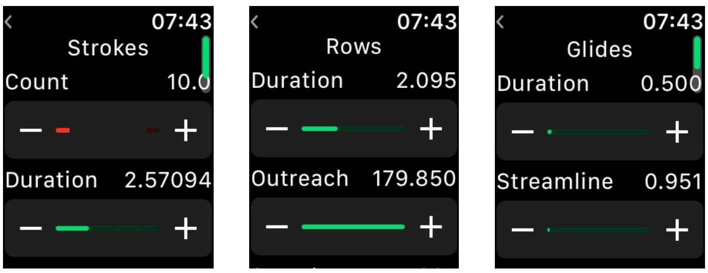

Fig. 5. The watch data pages – samples

The menu

For safe handling in the pool, the menu (fig. 6) reacts on strong and tightly focused pressing only. Thus the water waves around cannot tick the menu and the buttons.

The buttons on top start and stop recording.

The buttons on the bottom deal with data handling:

- Check activates the main screen so that a user can inspect the data of the current sample.
- Save sends data from up to 6 samples to the phone and cancels them on the watch.

A user starts the recording of a sample by pressing the swim button of the menu (see fig. 6). The app waits 3 seconds so that the user can launch, then the timer triggers sensor data shots (see table 1) 6 times a second, until the user stops data uptake by pressing the done button of the menu.

The done button returns the main screen. A strong tap there retrieves the menu. Now the options are to start a new sample, to check the data of the current sample, or to send up to 6 samples home to the iPhone.

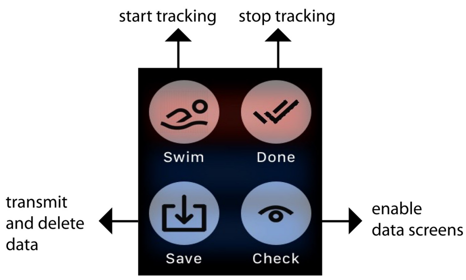

Fig. 6. The menu with buttons for use in the water

5.1 On the phone

General information

On the initial BreastStroke page (see fig. 7, left display), the HealthKit samples button leads to the personal swimming samples of the user.

Additional links with a red background go to internal how-to instruction screens and to the privacy page. Two instruction pages are shown in the middle and on the right of fig. 7.

Buttons with a blue background lead to some web advice pages on breaststroke swimming.

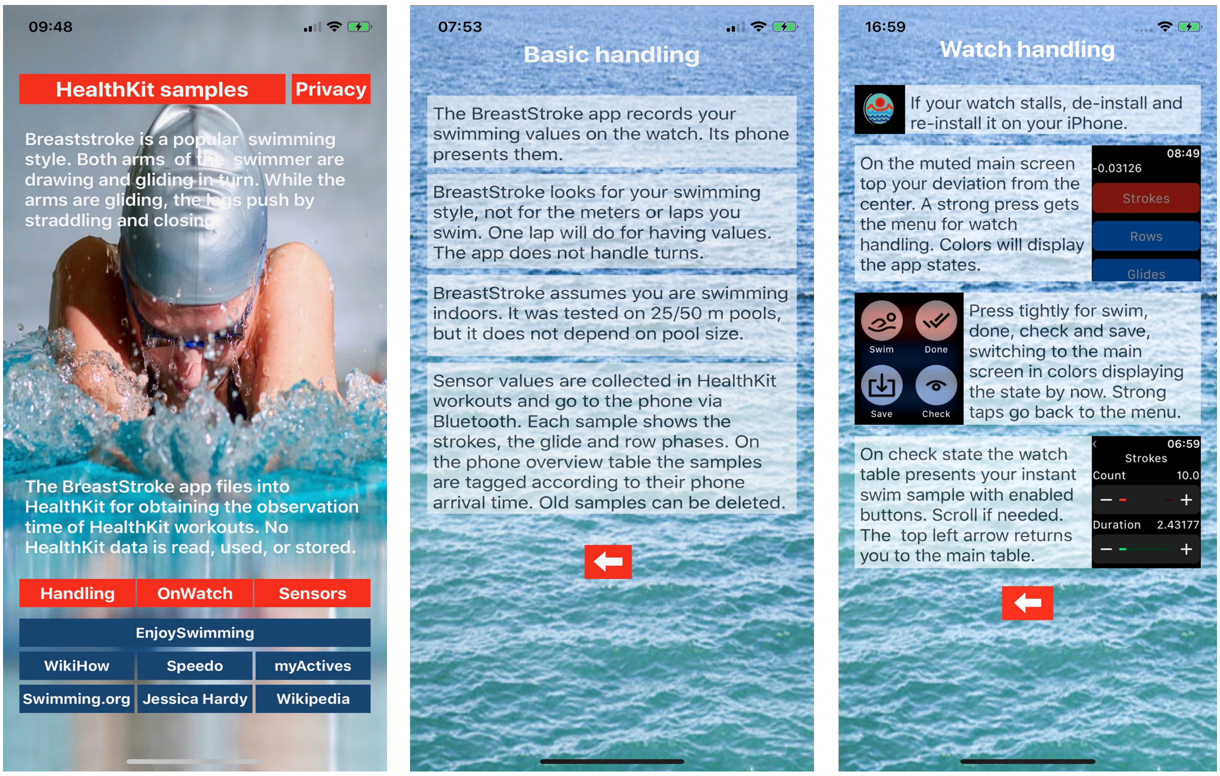

Fig. 7. Phone screens for general use: overview, basic instruction and instruction for watch use

```
// settings
glide: yaw -40° -- +40°
row: yaw -180° -- -40° or +40° -- +180°
unclear: any value

on timer shot
    get yaw value
    get roll value
    get acceleration value

    if glide
        after unclear
            // no action
            set glideStartTime

        after row
            // start new glide
            set glideStartTime
            glideNumber + 1

            // bookkeeping for finished row
            set rowTimeInterval
            strokeTimeInterval = rowTimeInterval
            set average rowTimeInterval

        after glide
            //keep best values if found
            set narrowerYaw if found
            set minRoll if found
            set maxGlideAcceleration if found
            set maxStrokeAcceleration if found

    if row
        after unclear
            //start first row and stroke
            set rowStartTime
            strokeStartTime = rowStartTime
            rowNumber + 1
            strokeNumber + 1

        after row
            //keep best values if found
            set widerYaw if found
            set maxRoll if found
            set maxRollAcceleration if found
            set maxStrokeAcceleration if found

        after glide
            // bookkeeping for finished glide
            set glideTimeInterval
            set average glideInterval

            // bookkeeping for finished stroke
            strokeTimeInterval = strokeTimeInterval + glideTimeInterval
            average strokeTimeInterval = average strokeTimeInterval + average rowTimeInterval

            // starting new row and stroke
            set strokeStartTime
            rowStartTime = strokeStartTime
            rowNumber + 1
            strokeNumber + 1

// end timer shot
```

Table 1. Pseudocode of sensor processing: handling a timer shot

User HealthKit samples

The collection of the user's swim samples is the main content of the iPhone interface. On the overview table (fig. 8, left display) the samples are listed according to their phone arrival time. Next to the heading, two buttons activate entry deletion (right) and the return to the normal table function (left). Deleting an entry is illustrated on the right side of fig. 8.

By tapping the entries users can switch to the more detailed reports on the samples (see below fig. 9) displaying the stroke, the row and the glide features on separate tables. All values are given in standard units: time in seconds, speedup in m/sec^2, and angles in degrees.

A user can like the values the BreastStroke app delivers or try to do something about them. In the present case the max palms-in value of -177° during the glides looks queer. It may be due to a turn in the swimmer's sample.

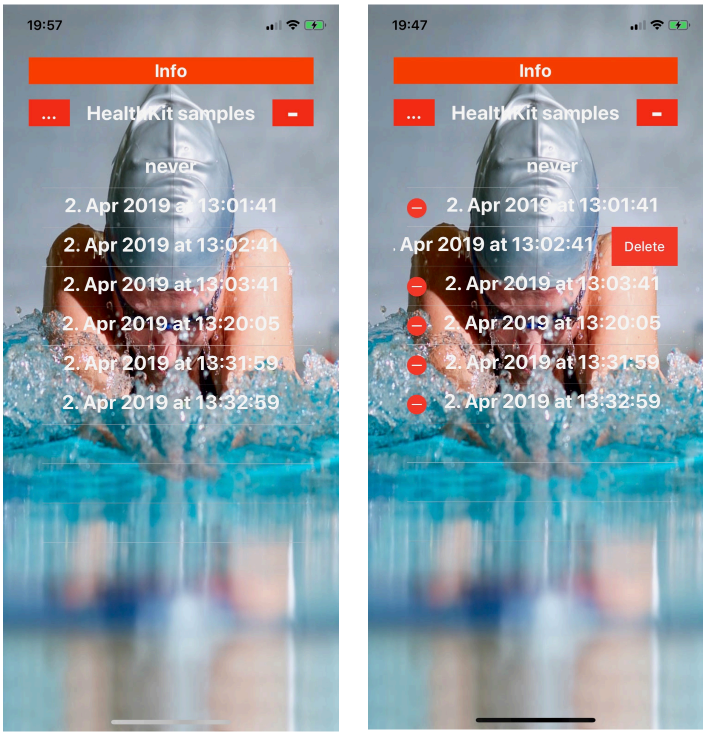

Fig. 8. BreastStroke overview table on phone. Red buttons next to the heading delete entries. Delete activated on the right display.

5. Conclusion

In comparison to other and earlier IMU applications, the watch seems to greatly simplify the life of swimmers and developers:

- Swimmers are at ease with the non-disturbing watch at their arm. They can inspect their values on the spot and in more detail on the phone.
- Developers are on safer and more confortable ground because the Core Motion API delivers preprocessed sensor values from the watch reference frame.

One may doubt the pertinence of the watch sensors values in general or because of assumptions of the breaststroke model:

- The mirror symmetry of left and right arm movements may be questioned.
- The simple stroke scheme of row and glide may not suffice for more sophisticated swimmers and trainers.
- The assumptions on the leg kick based on its timing during the arm glide may seem too poor.
- The empirical glide channel of 40° tested on one swimmer only might need to be adjusted/personalized.

All sorts of doubt are an invitation to test the BreastStroke app. The app is made for occasional swimmers. Nobody denies that competitive swimmers may need more detail, eg. , value sequences instead of key values, or sensor data recorded not on the wrist only. All this does not devaluate the BreastStroke app as a support of recreational swimmers. The author hopes to see more sophisticated watch apps for competitive swimmers in the near future.

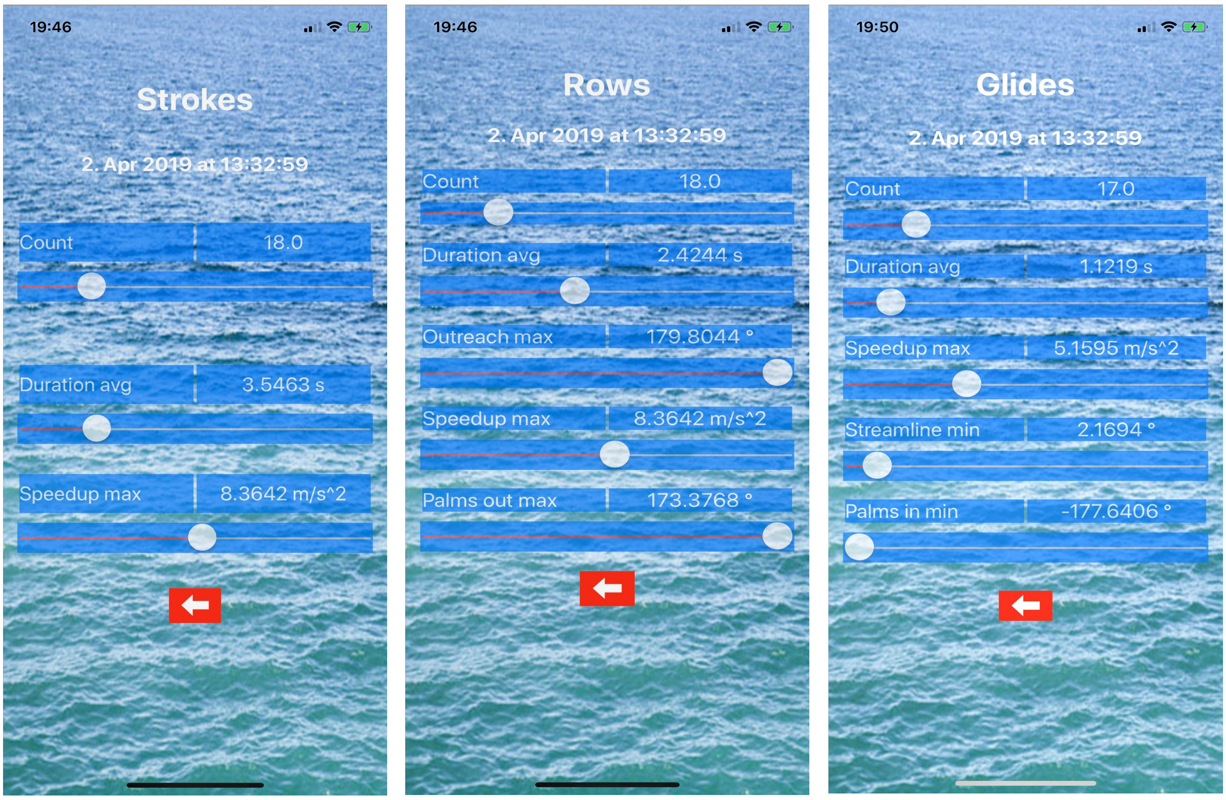

Fig. 9. Phone interface: Strokes, rows and glides display of a sample

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