SOUND FEEDBACK ON CADENCE FOR BLE SENSORS

Project Report

Abstract

Sound nRF Toolbox – An extended mobile application of nRF Toolbox that provides sound feedback in sync with cadence characteristic data.

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1. Introduction

Running with an auditory stimulus is a common practice e.g. listening to music or audio book for motivation or using mobile applications to improve running form. Many Mobile applications in the market tracks features such as heart rate, cadence, speed etc. Applications such as *Weav Run* and *Rock my run* adjust the songs' BPM (beats per minute) in sync with running cadence. However, such applications lack the capability to use an external sensor.

The mobile application in this project is an extension of the nRF toolbox application. In this report, the extended version will be referred to as Sound nRF toolbox; it connects to a BLE (Bluetooth low energy) device and provide audio feedback in sync with the provided cadence characteristic measurement.

2. Related Work

COMMERCIAL APPLICATIONS

There are several commercial apps and studies related to auditory feedback and cadence.
Weav Run is a commercial app that change songs' tempo to sync with runner's cadence in real-time. Users can also set their cadence goal and the songs will adjust to the settings.[1]

Another commercial is *Rock My Run*. Similar to Weav run, it matches music tempo to runner's strides. In addition, it has the option to match music to runners' heart rate. Unlike *Weav Run,* users set the music's tempo instead of the cadence. A limitation of Rock My Run is that it uses its own set of music rather than users' playlist.[2]

"PACEGUARD: IMPROVING RUNNING CADENCE BY REAL-TIME AUDITORY FEEDBACK" (FORTMANN ET AL, 2012)[3]

An academic study explored PaceGuard, a mobile phone-based system which supports runners in keeping their cadence by auditory feedback. "PaceGuard automatically determines a suitable target cadence on the basis of the measured sensor data of the first 30 seconds. After these 30 seconds, PaceGuard's acoustic feedback starts automatically. After the subsequent 120 seconds of running, the target cadence is adjusted according to the measured sensor data during these 120 seconds. This target cadence serves as the runner's guideline for the complete further run"[4] The result concluded positive results that auditory pulse does help runners maintain their cadence. However, the researchers did admit they had a small sample size of 5, and 2 of the participants stated that the auditory feedback required a lot of concentration, which is 40% of the total.

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[1] "Home," Weav Run, accessed August 21, 2020, https://run.weav.io/.
[2] The RMW Team, "RockMyRun, Music That Moves You," RockMyRun, accessed August 21, 2020, https://www.rockmyrun.com/.
[3] Jutta Fortmann et al., "PaceGuard," *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services Companion - MobileHCI '12*, 2012, https://doi.org/10.1145/2371664.2371668.
[4] Ibid.

3. Applications and Technology

STRYD

Stryd is a second-generation foot pod. Stryd use 9-axis sensors which combine accelerometers, gyroscopes, and magnetometers to achieve high accuracy. Older foot pods typically use 3-axis accelerometers. It is the first tool built for runners to measure the wind. Stryd reports the extra power (in watts) required to overcome air resistance[5]. Other metrics includes: pace, distance, elevation, running power, form power, ground contact time, vertical oscillation, leg stiffness and most importantly cadence.

BLE COMMUNICATION

Sound nRF toolbox connects to the Stryd through BLE (Bluetooth Low Energy) technology. A BLE device can act as a central or peripheral role, also can be referred to as client or server, respectively. The central (client) role initiates requests and accepts data responses, while the peripheral receives requests and return responses. In this project, the Sound nRF toolbox application will act as the central device, and the Stryd foot pod will act as the peripheral device. BLE uses a hierarchical data structure to define the information exchange structure.

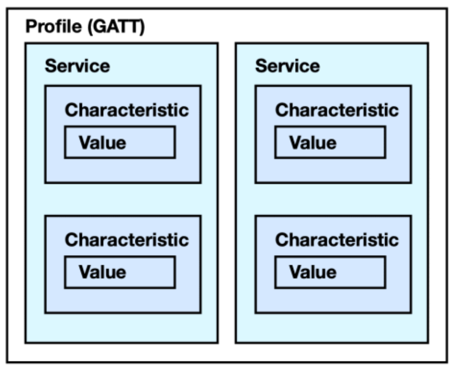

Figure 1 – BLE hierarchical data structure

GATT (Generic Attribute Profile) describes in detail how attributes (data) are transferred when once the devices have a dedicated connection. It makes use of a generic data protocol called the Attribute Protocol (ATT), which is used to store Services, Characteristics and other related data. A Service is a collection of characteristics. Characteristics are parts of the service that represents a piece of information/data exposed to a client. For example, A service called "Heart Rate Monitor" includes characteristics such as "heart rate measurement."[6]

nRF TOOLBOX

The nRF Toolbox is an application developed by Nordic Semiconductor. It works with a wide range of the most popular Bluetooth LE accessories which contains applications demonstrating the following profiles: Cycling Speed and Cadence, Running Speed and Cadence, Heart Rate

[5] Matt Wilcox, accessed August 26, 2020, http://www.stryd.com/.
[6] “Bluetooth Low Energy Overview: Android Developers,” Android Developers, accessed August 16, 2020, https://developer.android.com/guide/topics/connectivity/bluetooth-le.

Monitor, Blood Pressure Monitor, Health Thermometer Monitor, Glucose Monitor, Proximity Monitor and Nordic UART.[7]

To connect to Stryd with nRF toolbox:

Step 1 – Open nRF Toolbox app

Figure 2 – Start Menu of nRF Toolbox

Step 2 – Choose designated service

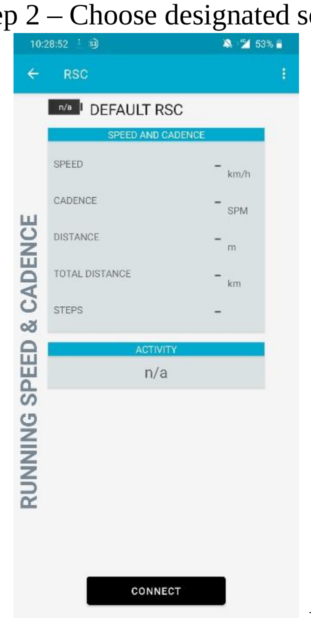

Figure 3 – RSC Display

Step 3 – Tap on *connect* after turning on Bluetooth

[7] "NRF Toolbox App," Nordic Semiconductor, accessed August 16, 2020, https://www.nordicsemi.com/Software-and-tools/Development-Tools/nRF-Toolbox.

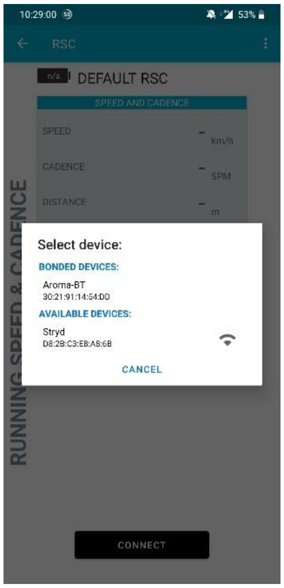

Figure 3 – Select Device display

All the devices within the proximity that advertises RSC data will be listed. Select the desired device e.g. Stryd.

Step 4 – Generate data in real time.

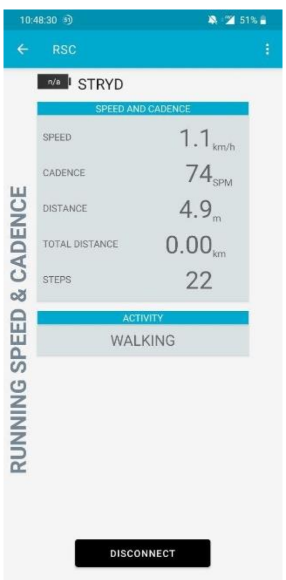

Figure 4 – RSC data detected

4. Sound nRF Toolbox Development

Sound nRF Toolbox is this project's application, it is an extended version of nRF Toolbox. There are total of four versions/drafts throughout the development process. Each version includes tweaks, fixes, and improvement in stability, resourcefulness and customization to the previous version. Oneplus 6T (Oxygen 10.3.5) and Oppo F5 (Android 7.0) were used to test Sound nRF Toolbox.

SOUND NRF TOOLBOX 1.0

The display of the original nRF Toolbox cadence metric is incorrect. The nRF Toolbox displays SPM (steps per minute). However, the measurement shows RPM (revolutions per minute). This can be confirmed by comparing different apps.

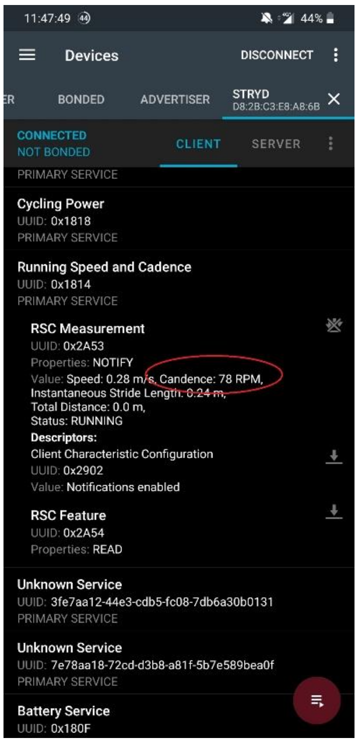

Fig 5 – nRF Connect

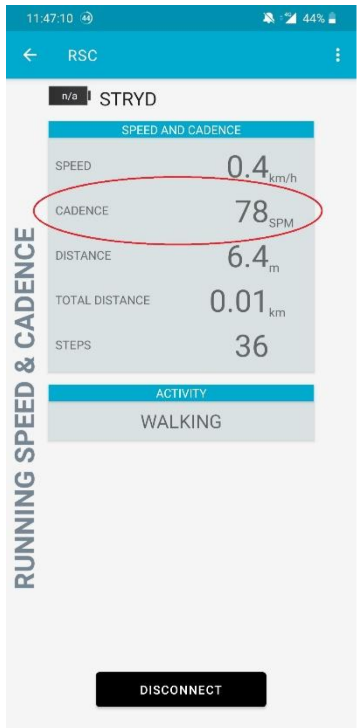

Fig 6 – nRF Toolbox

Fig 7 – Stryd app

nRF Connect is another tool to scan and explore Bluetooth Low Energy devices for communication.[8] Both nRF Connect and nRF toolbox cadence is at 78 (fig 5 and fig 6). nRF connect measure the data as RPM, while nRF Toolbox displays it as SPM. The correct SPM is ranging around 150-156 which can be seen on the Stryd app. This verifies that the nRF Toolbox metric is incorrect. SPM = RPM × 2. To convert SPM to RPM, we double the intake of the nRF toolbox cadence data.

To extend nRF Toolbox into Sound nRF toolbox, a mp3 formatted tick sound of 0.3 seconds was imported to sync with the cadence data. In this version, sound was synced in ranges (e.g. 0-15 SPM = Tick per 4 seconds; 16-30 SPM = Tick per 2 seconds; 120 SPM = Tick per 0.4 seconds).

Issues with version 1.0

[8] "NRF Connect for Mobile," accessed August 24, 2020, https://www.nordicsemi.com/Software-and-tools/Development-Tools/nRF-Connect-for-mobile.

There were stability problems with this version. The duration of the sound was too long. A cadence of 180 SPM equals to 0.33 seconds per tick and additional time is needed for data to travel between the sensor and the app. In addition, the player within the code needs to replay the mp3 file constantly. This is resource intensive, leading to more delay. This also resulted hearing double ticks occasionally. Instability occurs especially when cadence was between range switches e.g. fluctuating between 151-160SPM and 161-180 range.

SOUND nRF TOOLBOX 2.0

In this version, the initial 0.3 tick sound was cut to 0.15 seconds. The ranges were removed. Instead, it syncs in every tick. The double tick problem was greatly reduced, but still occurs seldomly.

Issues with version 2.0

Instability issues still occurs due to the constant replays from the media player. When the sound is reduced lower than 0.1 seconds, the sound was no longer functional in the Oneplus 6T (Oxygen 10.3.5) phone. Sound quality and smoothness was lost on the Oppo F5 (Android 7.0). The Android 10 update may have cancelled all mp3 audio that are below 0.1 seconds.

SOUND nRF TOOLBOX (3.0)

A tone generator was used in placement of the mp3 file. Tone generator use sounds that are native to Android. Thus, a media player was no longer needed to be imported in the code. This skips the constant media player replays. Most tones are longer than 1 second. Thus, the tone generator was coded to only play the first 0.025 seconds. Sounds native to android are still playable below 0.1 seconds and more resourceful. The stability issue was successfully fixed.

Issues with version 3.0

Having continuous feedback can be distractive to runners.

SOUND nRF TOOLBOX (FINAL)

Van Hooren et al. (2019) reviewed three types of effective auditory feedback at instantly modifying (running) technique. Auditory real-time feedback can be provided as I) verbal information whereby the wearable/clinician provides spoken feedback, II) an auditory alarm whereby a sound without any modulation is played if a variable exceeds the predefined threshold, or III) using sonification whereby the error between actual and desired performance is indicated by varying auditory variables. Real-time feedback wearables research indicates disadvantages of continuous feedback; it can be perceived as annoying and that individuals can become dependent on the feedback, which hinders learning. Methods that provide feedback less often are therefore usually preferred. One of these methods is bandwidth feedback, which involves providing feedback only when performance (e.g., heart rate) falls outside of a predetermined range.[9]

In the final version, the sound feedback enables for 2-minutes. At the end of the 2-minutes, the present cadence serves as the predefined threshold. As long the present cadence stabilizes within 15 range, the sound gets disabled after the initial 2-minute. If it deviates from the present cadence by 15, the sound re-enables for another 2-minutes. With this system, runners do not receive constant feedback when their cadence stabilizes. The sound serves as an auditory alarm and a compass to help runners find their ideal cadence.

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[9] Bas Van Hooren et al., "Real-Time Feedback by Wearables in Running: Current Approaches, Challenges and Suggestions for Improvements," *Journal of Sports Sciences* 38, no. 2 (2019): pp. 214-230, https://doi.org/10.1080/02640414.2019.1690960.

The Test

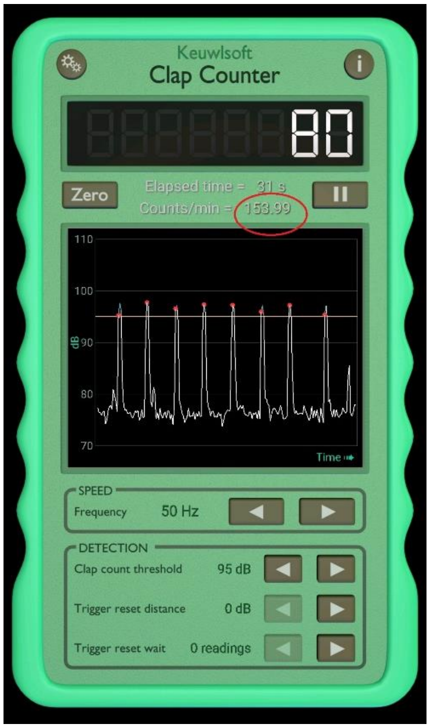

Fig 8 – Clap Counter

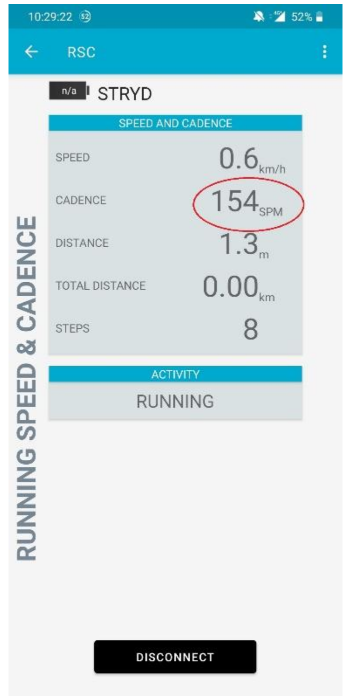

Fig 9 – Sound nRF Toolbox

A counter app was used to compare the tick sequence with Sound nRF Toolbox. Clap counter is an app that captures sound events and counts the tick per minute, frequencies, time etc. Comparing Fig 8 and Fig 9, the Clap Counter and Sound nRF Toolbox both detects 154 ticks per minute.

5. Future Work

Sound nRF Toolbox can be adapted into commercial apps such as Weav Run and Rock my Run, with the feature to connect to BLE sensors such as Stryd. There are other ways to update/improve Sound nRF Toolbox. According to a study on *The Effect of Gamification in Sport Applications*, application are mostly used to monitor users' workouts to complete the weekly planned routine (Statement: "I like to see that I completed all the workouts I have planned"), or to see progression, (Statement: "I am only satisfied with a workout, if I broke any of my personal records") received also high points in feature influence ranking.[10] A good example would be to complete a challenge, where the user needs to reach a stable

[10] Aron Toth and Emma Logo, "The Effect of Gamification in Sport Applications," *2018 9th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, 2018, https://doi.org/10.1109/coginfocom.2018.8639934.

cadence for a certain duration.

Experiments on performance could also be conducted to test whether using Sound nRF toolbox impacts performance. Past research studies have compared running performance on acoustic-stimuli versus non-acoustic stimuli; and the results does show improvement in performance with acoustic stimuli. However, there seems to be contrasting results whether there is a performance difference between music and metronome feedbacks.

"The Power of Auditory-Motor Synchronization in Sports: Enhancing Running Performance by Coupling Cadence with the Right Beats"[11]

The objective of the study was to examine the relative effects of auditory-motor synchronization and the motivational impact of acoustic stimuli on running performance. 19 participants ran to exhaustion on a treadmill in:

1) A control condition without acoustic stimuli.
2) A metronome condition with a sequence of beeps matching participants' cadence (synchronization)
3) A music condition with synchronous motivational music matched to participants' cadence (synchronization and motivation).

Time to exhaustion was significantly lower without acoustic stimuli. Surprisingly, time to exhaustion did not differ between metronome and motivational music conditions, regardless of motivational quality. Participants ran significantly longer with acoustic stimuli. The time to exhaustion did not differ significantly between metronome and music conditions.[12]

"Effects of synchronous, auditory stimuli on running performance and heart rate"[13]

The purpose of this study was to examine:

1) the contrast between the influence of no auditory stimulus and accelerated auditory stimuli (by 2% of the runners' original cadence, as this is the maximum of spontaneous increase) on running performance.
2) the influence of listening to music compared to listening to a metronome on running performance."

28 participants performed two cooper tests. The participants were divided into two groups. Both ran without acoustic stimuli on the first run. The second run, group 1 ran with music while group two ran with metronome. The results revealed a significant effect of an acoustic stimulus on the accomplished running distance in second run in comparison to the first run (+61 m ± 100) (p=0.001). 75% of all athletes achieved a greater distance under the influence of an acoustic stimulus.

Listening to music in run 2 thereby caused a distance enhancement in 85.7% of the runners of group 1. Compare to 64.3% of the participants performing run 2 in the presence of a metronome

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[11] Robert Jan Bood et al., "The Power of Auditory-Motor Synchronization in Sports: Enhancing Running Performance by Coupling Cadence with the Right Beats

[12] Ibid

[13] Lisa Maria Pfleiderer et al., "Effects of Synchronous, Auditory Stimuli on Running Performance and Heart Rate," *Current Issues in Sport Science (CISS)*, December 2019, https://doi.org/10.15203/ciss_2019.005.

increased their running distance.[14] Music seems to enhance performance to a greater degree than the sound of a metronome, which might be due to the more motivational qualities of music. The melody and rhythm of a musical piece was determined to distract the exerciser from feelings like pain, discomfort and fatigue.[15]

Both studies demonstrated improvement in performance with acoustic stimuli. However, there is contrast results whether there is a significant difference between music and metronome stimuli in terms of performance enhancement.

6. Conclusion

The sound synchronisation was successfully implemented to the nRF toolbox with a BLE cadence sensor. By using sounds native to android, the application was able to stabilize and reserve phone resources. To prevent continuous feedback distraction, the final version of Sound nRF Toolbox only enables for 2-minutes unless the present cadence deviates by 15. The accuracy of the Sound nRF Toolbox was tested with Clap counter app to confirm the sound sequence timing. For future work, adding routine tracking and challenge features will increase motivation for usability because sport application users prioritize data analysis and progression.
Running with auditory feedback, either with metronome or music has shown to have positive impact on performance. Additional experiments need to be conducted to explore the contradicting results between the study of Pfleiderer et al. (2019) and Bood et al. (2013) whether there is a significant difference in running performance between music and metronome stimuli.

[14] Pfleiderer et al., "Effects of Synchronous, Auditory Stimuli on Running Performance and Heart Rate,"
[15] G Tenenbaum et al., "The Effect of Music Type on Running Perseverance and Coping with Effort Sensations," *Psychology of Sport and Exercise* 5, no. 2 (2004): pp. 89-109, https://doi.org/10.1016/s1469-0292(02)00041-9.

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