EasyBreathe: Heart Rate and Accelerometer Components Report

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***Abstract*—EasyBreathe is a system that notifies the user when they are stressed and allows them to use exercises to reduce it. One of they key components is to employ sensors that detect the heart rate and the movement that then determine the condition of the user. In order to achieve this feature we are going to use an Apple Watch because it has both sensors that we require and because we're able to use the display to engage the user.**

I. Introduction

The first stage is to perceive the physiological state of the user and in the case of our system the aim is to detect whether the user is in a state of stress. There are several factors that play an important role in order to identify whether a person is stressed or not. Two of the most important ones are linked to the heart rate of the person and the amount of body movement [1], therefore we need sensors that can measure the pulse and an accelerometer that can quantify body movement. Both of these sensors are nowadays included in many commercially available activity trackers and smartwatches.

The measurements would be sent to the main component, a smartphone, where the data is processed and evaluated. Once it has been determined that the user is stressed we want our system to notify the user non-intrusively and optionally engage the user in breathing exercises that can reduce the stress.

In this report I will cover the research that has been completed that measures and quantifies stress, then discuss the requirements of the sensors that we would use for our system and why we have settled on the chosen component and finally showcase some ongoing work and what the implementation has been so far.

II. Related Research

As outlined one of the major features of our system is to detect stress in a user. In order to do so there are various methods one could apply, ranging from surveys to measuring physiological signals of a patient. There has been a lot of research undertaken to measure stress physiologically and there are a couple of indicators. Poh et al. [4] developed a wrist-worn integrated sensor that allowed the researchers to detect whenever a patient were stressed by observing the electrodermal activity. The findings showed an increase in galvanic skin response (GSR) whenever there was prolonged activity, validating GSR as one of the factors that can be linked to stress. Vrijkotte et al. [3] measured the amount of stress induced by the patients' work environment by measuring the patients' blood pressure, heart rate (HR) and heart rate variability (HRV). The findings showed a clear correlation between the state of the patient and the levels of the indicators.

This study is one of many that has shown that HR is intrinsically linked to stress. Boonnithi et al. [5] have shown that many heart rate features, including the mean heart rate, which is measured in beats per minutes (BPM), are strong indicators of the mental state of the patient. Min et al. [1] have conducted experiments where they measured mental activity with patients in motion and while resting; to quantify the motion they used accelerometers, which sensed movement. Among the main indicators they linked to stress were the mean HR, mean HRV and R-R interval, as well as the average energy of the accelerometer. Noteworthy is that the time of the day is also a key feature to consider, because due to the circadian rhythm there can be an increase in the heart activity without being linked to stress. Feng-Tso et al. research [2] reinforced these findings, by demonstrating that body movement itself causes an increase in HR, therefore HR alone can't be used as an indicator for stress, it needs to be measured in context with how much the user moves.

There are two technologies that can measure the heart rate of a person: Electrocardiography (ECG) and photoplethysmography (PPG) [8]. ECG measures the heart rate by using the electrical signal produced by the heart activity, PPG uses LEDs whose light is absorbed by the blood flow. Commercial smartwatches and many activity trackers use PPG to inform their user about their heart rate by displaying the rate in BPM. Lu et al. [7] have shown that PPG is prone to noise and error due to movement. This is something that is going to be considered when collecting data. It has been further shown that PPG is not optimal to detect HRV [6], but performs well when measuring the mean HR.

Parallel to detecting stress there has been a lot of research trying to validate the effectiveness of methods that can reduce stress. There are many approaches that are used to calm a patient and one of the most common and effective methods are breathing exercises. Several studies, including Brown's [9] have shown the effectiveness of focusing the user on their breathing and the benefits it has on diminishing stress-related symptoms.

III. Requirements

The preliminary research founded the specifications that we looked out for when researching for applicable heart rate and accelerometer sensors. One of our preliminary design choices was to use the Apple platform when designing our solution, therefore making Swift our target language. We chose Apple because it allows to make use of HealthKit, Apple's Health Data Storage API, and therefore easily store data securely [10]. Since we chose to build with the Apple Platform and therefore use iPhones as our main component to evaluate data we needed our sensors to be compatible with iOS.

A recent survey from Forrester indicated that the most popular place on the body to have sensors placed would be on the wrist, followed by the sensors being clipped on the clothing [11]. There are many heart rate sensors that are worn on the chest, however this is an unpopular place to wear. We therefore looked out for sensor that can be worn on the wrist and in order to not have the user wear more than one sensor at once and to ease development, we require the two sensors to be incorporated into one single device.

As described, PPG has some disadvantages and is only able to detect the mean HR, not to measure HRV, which has been described as a more reliable indicator for stress [2]. We are however confident that we can determine the user's state using mean HR by taking the measurements in context of body movement. If the user is in rest and the HR increases it would be a strong indicator that the user is becoming stressed. We therefore don't need a accurate readings when the user is motion a lot which also helps to alleviate the issue with noise as PPG is not accurate when the user is moving.

There are very few mobile wrist worn sensors that are able to track HRV. Furthermore, if we were to use HRV we wouldn't be able to use HealthKit as it doesn't include any classes for HRV. This would make it more difficult to securely store the data or develop with Swift.

In order to measure body movement we need our sensor to include an accelerometer. The iPhone itself has an accelerometer, however it wouldn't be able to detect any movement in case the user doesn't have the phone with them, for example by placing it on a table. Hence a separate accelerometer to the iPhone's is required when comparing sensors.

One of the main feature we envision our wearable sensor to offer is to non-intrusively notify the user of elevated stress levels, but also allow to alleviate the state by offering breathing exercises. The most subtle way of notifying would be a small vibration, but visual cues, like LEDs of an activity tracker or a display of a smartwatch flashing would also accomplish this feature. Using a display would make it more practical to visualise a breathing exercise for the user to engage with as compared to using LEDs.

Not directly linked to the performance of detection, yet important, is the power consumption that constant sensing would impose. Activity trackers are designed to solely track heart rate and steps and can therefore last for a long time without recharging. However, smart watches are designed for more applications and are not designed to continuously measure these factors.

Taken all these requirements into consideration there are a handful of commercial smart watches or activity trackers that we could use. The majority of the devices use PPG to detect the heart rate and whilst many have built-in accelerometers, they are used for tracking for steps and are not accessible for developers, for example in Fitbit's devices [18].

Comparing various sensors smart watches, shown in Figure 1 on page 4, the Apple Watch stood out as the best sensor for us to use. There are some complications due to Apple's restrictions regarding the access of some of the watch's features, but it should be possible to work around these. The watch uses the latest operating system Watch OS 2 and can be easily adapted to an iOS application. The watch uses PPG and when not actively tracking the heart rate, the watch measures the pulse every 10 minutes. When starting a workout, the watch measures the heart rate in a 5 second interval. Additionally the watch gives developer direct access to the accelerometer.

IV. Related Work

There are a couple of apps that aim to detect stress. In terms of detecting heart rate and notifying the user the app *Chill* by Nathan Hekman [12] achieves this feature. His app detects the user's heart rate and compares it with a predefined "chill" heart rate. If the user's heart rate rises above this chill level the user is notified that "they need to chill". Nathan doesn't make use of the accelerometer in order to exclude deviation in heart rate due to movement, nor is he considering any other factors that could influence his application.

The *Calm* app developers state they can detect stress [13], however their claim is not backed by any evidence. Additionally they state that they are able to measure several factors apart from HR, such as GSK, however these aren't integrated sensor of the Apple Watch. Therefore it seems that this application is only hypothetical.

The *3 Minute Mindfulness* app of Honeyseed Limited [14] utilises the breathing exercise on the Apple Watch by displaying an animation with instruction. Their app focuses solely on the breathing exercise, they don't measure or quantify the level of stress or take any of the stress-related factors into account.

The Health Care Service Corporation are taking a different approach to monitor stress [15]. They have devised an application *Centered* that prompts the user on a regular basis how mindful they feel and depending on their state the user can follow some exercises that improve their state. Similar to the other apps, *Centered* does not measure any physiological signals.

There aren't any public libraries available for Apple Watch developers to use to build their applications. There are however open source projects that we are using in order to build our system on the Watch. The project *watchOS-2-Sampler*, developed by Shuichi Tsutsumi [16], is a good source for forming the baseline of accessing various features of the Apple Watch, such as the heart rate sensor and the accelerometer. Brad Larson has developed an application *HealthKit Heart Rate Exporter* [17] that allows to extract the stored heart rate data in HealthKit to a CSV format. This project can be used to build part of the data extraction system on the iPhone.

V. Implementation

I have developed two small prototypes to use the accelerometers and the heart rate sensor of the Apple Watch.

When we observe the state of the user we want to measure their heart rate continuously. In an idle state, the Apple Watch measures the heart rate every 10 minutes, which is not quick enough to determine which state the user is in. With the use of Apple's HealthKit we can start sensing the user's heart rate every 5 seconds. The problem is though that in order to get a constant sensing of the heart rate we need to start a workout as Apple has restricted the access of the heart rate solely for workout purposes. When doing a workout the app is working in the foreground but it would also require the app to be opened and activated by the user manually. One solution is to design the application so that the user chooses when to monitor his stress levels. This could be achieved by having a button stating ”Start stress tracking”. The heart rate is written to HealthKit and can be accessed from there from the phone as demonstrated in Larson’s work [17].

In order to measure the body movement of the user we make use of the accelerometer. To access the accelerometer we use CoreMotion platform of the Watch OS. The prototype at the moment requires the user to start sensing the accelerometer; the values of it are written to an array continuously. The sampling is called by a timer and therefore we can set the frequency of the sampling by changing the timer. Once the user has stopped writing values to the array the user can send the values to the phone.

There are several methods to send data between an Apple Watch and an iPhone. The core framework to use that was introduced with Watch OS 2 is WatchConnectivity. There are different methods of communication, one is interactive messaging, which allows instant transfer of data when both the Watch and the Phone applications are active. We were able to pass data from the Watch to phone via interactive messaging. At this point the user needs to send the data by pressing a button, but by having a timer it should be possible to send the data automatically to the phone without the user’s need to prompt the transfer. I have quickly built an app for the phone that can display the array in a table to verify that the array has been sent and that it can be read, validating the interactive message method.

One problem that I have noticed is that the Watch stops recording the accelerometer data once the screen deactivates via movement of the wrist. This is not ideal as we need to continuously write data, but by integrating the recording into a workout it should allow us to record even when the Watch is deactivated. A second issue that we need to fix is that both of the applications need to be active.

The next steps apart from addressing the issues would be to combine both of the prototypes and to automate the data collection. As described it should be straightforward by integrating both sensors into one workout session.

After the data has been successfully collected and sent to the iPhone we require the second feature of our system, to notify the user of their state and to offer relaxation methods. We are going to design an interface that displays the breathing exercise.

VI. Conclusion

Being able to detect the heart rate and sense body movement of the user with an accelerometer are integral parts of our system to determine whether a user is stressed. I have developed two prototypes that allow to access the accelerometer and heart rate sensor and demonstrated how both measurements can be accessed from the phone. I have highlighted the difficulties we might encounter and potential solutions.

References

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Sensors	Manufacturer	Type of Device	Screen	Body Part	Compatible with iPhone	3-Axis Accelerometer	Type of HR Sensor	Detect Heart Rate	Detect Heart Rate Variability	Other Features
Apple Watch	Apple	Watch	Touch and Colour	Wrist	Yes	Yes	PPG	Yes	No	-
BioHarness	Zephyr	Tracker	No	Chest	No	No	ECG	Yes	Yes	Detect R-R
HxM Smart	Zephyr	Tracker	No	Chest	Yes	No	ECG	Yes	Yes	Detect R-R
HxM BT	Zephyr	Tracker	No	Chest	No	No	ECG	Yes	Yes	Detect R-R
Fitbit Zip	Fitbit	Tracker	No	Clip	Yes	Yes	No	No	No	-
Fitbit One	Fitbit	Tracker	No	Clip	Yes	Yes	No	No	No	-
Fitbit Flex	Fitbit	Tracker	No	Wrist	Yes	Yes	No	No	No	-
Fitbit Charge	Fitbit	Tracker	OLED	Wrist	Yes	Yes	No	No	No	-
Fitbit Alta	Fitbit	Tracker	OLED	Wrist	Yes	Yes	No	No	No	-
Fitbit Charge HR	Fitbit	Tracker	OLED	Wrist	Yes	Yes	PPG	Yes	No	-
Fitbit Blaze	Fitbit	Tracker	Touch and Colour	Wrist	Yes	Yes	PPG	Yes	No	-
Fitbit Surge	Fitbit	Watch	Touch and Mono	Wrist	Yes	Yes	PPG	Yes	No	-
Samsung Gear S2	Samsung	Watch	Touch and Colour	Wrist	No	Yes	PPG	Yes	No	-
Moto 360	Motorola	Watch	Touch and Colour	Wrist	Yes	Yes	PPG	Yes	No	-
Moto 360 Sport	Motorola	Watch	Touch and Colour	Wrist	No	Yes	PPG	Yes	No	-
SmartBand 2	Sony	Tracker	No	Wrist	Yes	Yes	ECG	Yes	Yes	-
SmartBand Talk SWR30	Sony	Tracker	Mono	Wrist	No	Yes	No	No	No	-
SmartWatch 3 SWR50	Sony	Watch	Touch and Colour	Wrist	No	Yes	No	No	No	-
vívoactive® HR	Garmin	Watch	Yes but no apps	Wrist	No	Yes	PPG	Yes	No	-
Huawei Watch	Huawei	Watch	Touch and Colour	Wrist	Yes	Yes	PPG	Yes	Not specified	-
Mio FUSE	Mio	Tracker	OLED	Wrist	Yes	Yes	PPG	Yes	No	-
UP Move	Jawbone	Tracker	No	Clip	Yes	Yes	No	No	No	-
UP 2	Jawbone	Tracker	No	Wrist	Yes	Yes	No	No	No	-
UP 3	Jawbone	Tracker	No	Wrist	Yes	Yes	ECG	Yes	Not specified	Measure respiration & GSR
Reign	Jawbird	Tracker	No	Wrist	Yes	Yes	ECG	Not specified	Yes	
Mio Alpha	Mio	Tracker	Mono	Wrist	Yes	Yes	PPG	Yes	Not specified	
Mio Link	Mio	Tracker	No	Wrist	Yes	No	PPG	Yes	Not specified	
TICKR X	Wahoo	Tracker	No	Chest	Yes	No	ECG	Yes	Not specified	
MZ-3	MyZone	Tracker	No	Chest	Yes	No	ECG	Yes	Not specified	
Polar A360	Polar	Tracker	Yes	Wrist	Yes	Yes	PPG	Yes	No	
Polar Loop 2	Polar	Tracker	No	Wrist	Yes	Yes	No	No	No	Can be combined with HR sensor
Polar A300	Polar	Tracker	Mono	Wrist	Yes	Yes	No	No	No	Can be combined with HR sensor
Polar M400	Polar	Watch	Mono	Wrist	Yes	Yes	No	No	No	Can be combined with HR sensor
Polar H7	Polar	Tracker	No	Chest	Yes	No	Yes	Yes	Yes	Can be combined with tracker

Fig. 1: Comparisons of commercially available sensors