StudyBuddy: Continuous Heart Rate Monitoring Component Report

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Abstract— **StudyBuddy users will often get stressed during heavy periods of procrastination. It is imperative for the StudyBuddy application to record peak periods of stress within users during study sessions to provide data for later usage by the recommendation component. To achieve this a Moto 360 Android wear device will be used to monitor the heart rate of the user.**

I. Introduction

Procrastination while studying leads to an onslaught of stress brought on by poor time management and ineffective study routines [1]. StudyBuddy is a mobile healthcare system designed to record a study session, examine points of procrastination experienced during the study session and provide recommendations to the user that could help them improve their study schedule. Given that there is an inherent link between academic self efficacy[1] and stress [2] it is important to obtain real-time measurements of a users heart rate during the study session.

The measured heart rate values will then be sent to the StudyBuddy application hosted on Android smartphone. In the application further processing will be done on the HR (heart rate) values such as statistical displays and machine learning (which is further explored in the recommender module).

This report will cover the research done on stress and its link to procrastination followed by a research analysis on HR measuring techniques, it will then highlight the decisions that ultimately led to the use of the selective HR measuring component, followed by a short discussion on ongoing work in the field of recognizing stress by measuring HR in commercial applications and exclusive applications that help with procrastination and finally an implementation plan that details all the work done on the HR measuring component so far.

II. Related Research

Stress is defined as *"A state of emotional strain or tension resulting from adverse or demanding circumstances"* [3]. Academic procrastination is a serious issue as it ultimately leads to stress [4]. This is also supplemented by the positive correlation between approaching deadlines and an increase in stress levels due to procrastination [5]. Some studies related to undergraduates have also found that around 75-90% of undergraduates procrastinate [6], [7]. In conclusion, the scientific community is riddled with various instances of academic procrastination and an increase in stress levels which implies that stress is an important factor that needs to be quantified.

Stress can be measured through various means. One of the most popular methods involved in measuring stress is the perceived stress scale [8] which is a questionnaire designed to rank stress in an individual based on the answers given. Stress causes various phenomenons in the human body and as a result these physiological changes can be measured to establish a quantitative measure of psychological stress in a person. GSR (Galvanic Skin Response) [9] has shown great reliance in measuring stress with a positive correlation between stress and the response but this methodology cannot be replicated in real world settings, especially for the procedural operation of the StudyBuddy application. Stimuli that bring about mental stress trigger the autonomic nervous system, suppress the parasympathetic nervous system and activate the sympathetic nervous system which cause the secretion of epinephrine and norepinephrine which cause various changes in the vitals of a person such as an increase in blood pressure, increase in muscular tension and changes in HR and HRV[2] (Heart Rate Variability) [10]. While HR is a good indicator of stress it is nowhere near as accurate as HRV (particularly with Power Spectra models) [11]. HR is less accurate than HRV for stress as there is no reliable distinction between HR increments due to the movement of the body or due to stress. Unfortunately, HRV cannot be measured by Smart Watches but there is a way to mitigate the inaccuracy experienced by HR measurements for stress. By incorporating an accelerometer to measure the movement of the body relative to the HR can help determine reliable instances of stress [12] though this may not be necessary for the StudyBuddy application as users will be stationary while they are studying and the Computer Vision component will account for special cases (such as leaving the room or the study area) when the HR could be high.

HR monitoring is possible through various electrical mechanisms. There are two widely used HR monitoring tactics, namely ECG (Electrocardiogram) and PPG (Photoplythesmography) [13]. ECG signals measure the direct electrical activity of the heart by attaching sensors or electrodes to the skin. PPG is an optical sensor that uses LEDs (green LEDs in smart watches) to emit light and measure absorption as the blood absorbs the emitted light. By measuring changes in the absorption it is possible to work out the HR. It is a well known fact that PPG is less accurate than ECG [13] but PPG can still

[1]The confidence, in students, that allows them to carry out tasks like preparing for exams

[2]HRV is the time taken between each beat of a persons heart

be a reliable indicator of correct HR data particularly in the absence of motion artifacts [14].

III. Requirements

Now that we have established that HR can be a sufficient tool for measuring stress and PPG can be a relatively accurate method for measuring HR we will explore all the design choices that will help us select a PPG sensor for measuring HR.

The target platform agreed upon by the StudyBuddy team was Android [15] due to its wide use in the world and its user friendly development experience.

The placement of the sensor was a very important design choice. Some sensors can be worn as clips like Grove [16], others can be worn around the waist like the Polar T31 transmitter [17] and some are worn on the wrist (usually as smart watches like the Moto 360 [18]). We expect people to conduct their study sessions while they are seated and we expect movement to be minimal. This would allow a chest strap to be worn around the user as straps around the waist like the Wahoo strap [19] are more accurate than wrist sensors due to their short proximity to the heart. However for our design a chest strap would be unfavourable as integrating a chest strap with the entire system would be more difficult in terms of design complexity and support with Android and users would feel quite unnatural studying with an external load on their chest. For these reasons we decided to use wrist sensors.

Power consumption is also a major consideration as the wrist sensor will be polling data continuously throughout a study session that can last for hours. It is important to have a suitable polling rate to prevent great strain on the battery and the design requires each user to enable access to sensors before using StudyBuddy and unregisters the sensors when a study session is over. Section V will discuss the polling rate used for the application.

The table given below summarizes available wrist sensors, their compatibility with Android, their ability to measure HR and HRV and the type of sensor they use.

Name	Company	Type of Sensor	HR	HRV	Android Compatible
Moto 360	Motorolla	PPG	Yes	No	Yes
Apple Watch	Apple	PPG	Yes	No	No
Huawei Watch	Huawei	PPG	Yes	-	Yes
Reign	Jawbird	ECG	-	Yes	Yes
Helo LX	Wor(l)d	ECG	Yes	Yes	-

TABLE I
COMMERCIAL WRIST SENSORS FOR HR AND HRV

Table I shows certain wrist sensors from companies that can record ECG and consequently HRV which we have discussed as a more reliable indicator of stress in section II. Reign [20] appeared to be a suitable wrist sensor but there have been many reported problems with the sensor accuracy and its lack of integration with 3rd party applications (which would make development difficult) [21]. Helo LX [22] is not compatible with Android development and was therefore not considered. Given all of these requirements the Moto 360 [18] was selected as the component for sensing HR.

Instead of using Google Fit [23], which is a Health API designed by Google, StudyBuddy's HR sensing prototype detects the raw sensor values from the HR sensor. The only reason behind this design choice is that Google Fits API requires users to create a Google Account and login on it in the StudyBuddy application to grant permission. We believe it is better to keep the StudyBuddy application independent of any other party. While Google Fit does provide great features and secure data storage there is only a short data flow required for HR sensing namely the HR data between the Moto 360 and the Android phone followed by Firebase [24]. The data flow between the watch and the phone is encrypted and secure as it makes use of the Google API Client [25]. Firebase (the database) [24] can be made secure by using a login and password which is prompted on the startup of the app.

Other requirements before proper use of the component would include more information on the user of the StudyBuddy application before obtaining serious HR measurements to determine stress. HR can be affected by a persons weight, gender and age [26]. To accommodate these factors a users profile could be established in the application to account for most of them.

We also expect to add disclaimers before the use of the application as there are many external factors that could affect HR. Some examples that could render readings of stress from HR unreliable are:

- Caffeine (primarily found in coffee, tea, chocolates and soft drinks) [27].
- Post Exercise study session - There needs to be a grace period to allow the heart to settle at a resting BPM before making measurements [28].
- Any heart conditions (cardiomyopathys, inherited arrhythmias or high cholesterol levels) [29].
- Medications like Beta Blockers that could seriously change HR values [30].
- The temperature of the room - Our application will advise users to keep an appreciable temperature to validate the HR readings [26].
- The time of day [31].

IV. Related Work

Applications commercially available that specifically detect stress during procrastination are non existent. There are applications that perform both of these tasks independently and are discussed in this section.

A popular smart watch called Emvio specifically designed for measuring heart activity throughout a persons day possesses the capability to determine stress by working in tandem with an accelerometer to make precise measurements of stress [32]. Emvio also notifies the user when they get too stressed by making use of LEDs. Breathe2Relax [33] is a stress management application which relies on a user performing breathing exercises to reduce their stress, it does not actively monitor HR or any physiological components and is expected to be an application used when someone thinks that they are stressed. Pacifica [34] takes this one step forward and has a mood tracker and tools to help lower stress levels and also has a tool which helps record your own thoughts which help the user pinpoint reasons for stress. Personal Zen [35] has a series of games which are based on clinical studies that help in reducing stress and anxiety. All of these applications require subjective data to manage stress which can be circumspect. Stress Check [36] is an application that uses the camera and light on an Android phone to measure HR to detect stress. Although this approach works favourably, the smartphone running StudyBuddy must remain unused during a study session leaving wearables as the only instrument available for HR measurements.

Applications such as SelfControl [37] and Freedom [38] do help one eliminate procrastination but are not in conjunction with stress related apps or any measurements of HR.

V. Implementation Plan

This section includes the current implemented prototype used for continuous HR monitoring and observations with future suggested work on the component.

A. Heart Rate Sensing

To achieve continuous heart rate sensing I have made use of the sensors on a Moto 360. Android allows direct access to the sensors [39] present in any Android Wear device (provided they are available) under the method available to Android wear as `TYPE_HEART_RATE`. Instead of implementing HR sensing as a standalone application on the Moto 360 I have implemented it as a service [40] which consistently polls the data in the background if the application was launched once. There were many reasons for implementing the HR sensor as a service, particularly due to the watch's inability to keep the application open for extended periods (as a power safety feature). There was a need to poll data continuously for hours (depending on any average study session) which made a service with correct power saving methodologies all the more preferable. Another benefit of a service is that it could unregister (inactivate) sensors and therefore conserve the battery of the Moto 360 by using remote commands (like the stop button for a Study Session).

I have also implemented a companion application on the Android Phone which currently displays the heart rate of the user using the Moto 360 on the phone as a textview. In order to transfer the data from the watch to the phone I have made use of the Google API client library [25] for wearables. The connection between the phone and the watch is over Bluetooth. The delay between sending the data to the phone and receiving it on the watch is virtually negligible. This provides a good balance between useful readings and battery consumption.

The results below are measurements taken for the functional operation of the designed component. These results are **not indicative of stress** and are only designed to test the sensitivity of the component. The Moto 360 was used on a test subject on a treadmill to gauge changes in HR and intervals to record sensitivity. The test subject is a 21 year old male with no prior heart conditions or medications or any known congenital heart defects. The columns in table II are indicative of the pace (the speed of the treadmill over a period), Average HR (the average heart rate over a duration), interval (the time taken for the HR to reach the average value within a certain tolerance) and the Duration (the time for which a treadmill at a given pace lasts). The tolerance for the BPM (Beats per Minute) was kept as ± 6 BPM. Furthermore, there was a grace period of 8 seconds necessary for the pace of the treadmill to settle at the recorded value in the table, consequently the interval column is a reflection of values recorded from the time started after the grace period.

Pace (km/h)	Average HR (bpm)	Interval (s)	Duration (s)
0	77	5	60
3	101	4	90
5.5	137	6	90
10	183	6	60

TABLE II
Test values obtained for HR component

Average HR was calculated as $\sum_{i=1}^{N} \frac{HR_i}{i}$. Currently the HR sensor is polling data at 0.6 seconds (appropriate for any User Interface as this is `SENSOR_DELAY_UI`) [41]. The sensors are both sensitive and accurate which makes them a suitable choice for measuring stress in study sessions.

B. Observations & Future Work

Currently the HR model only sends HR data to the recommendation component. Our team believes that a classifier using machine learning algorithms to help classify stress will be quite necessary. I plan to extend my work on this component by working in tandem with my colleague who is designing the recommendation component to train a classifier that can classify stress. We plan to take inspiration from available studies such as stress classification using accelerometer and HR data [42] but we will incorporate already available data from the Computer Vision component to train our own classifier for stress detection.

The HR sensor outputs a 0 for around the first 10 seconds on average in the initial period before continuously displaying readings. This is an unavoidable hardware limitation from the PPG sensor and as a result readings obtained during this 'grace' period can be discounted, as they will not undermine the hypothesis. There is also more work to be done as these prototypes are standalone and are not linked to the entire system yet. The interface for the application on the Moto 360 only displays a textview of the current HR value, an improvement in its design could be more ergonomically feasible for the application but it may not be as heavily prioritized as integration. There are also more elements that could boost the operational capacity of the prototype, such as investigations into more effective polling rates (Android allows self-defined polling rates), battery consumption investigations with control apparatus and a potential integration of an accelerometer with the HR component as we have discussed the lack of credibility due to body movements with HR readings in section II.

VI. Conclusion

In conclusion, continuous heart rate monitoring for identifying stress in periods of heavy procrastination is a challenging task. To keep the design of my component simple and pragmatic I have implemented a continuous heart rate monitor on the Moto 360 smart watch, which has shown great promise in accuracy for heart rate measurements and therefore, appears suitable for measuring stress experienced during a study session.

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