A Smartphone-based Wellness Assessment Using Mobile Sensors

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***Abstract*—Developments in the Internet of Things (IoT) in recent years has allowed for wireless sensor data to be collected and communicated with more ease than ever. This facility of data acquisition has opened possibilities in a large variety of fields, including potential for a significant impact in health care. This paper introduces a framework using IoT sensors to examine correlations between environmental conditions and overall wellness. The proposed system uses a SimpleLink Bluetooth SensorTag and a mobile application to collect environmental data from a subject's surroundings on a daily basis. The participants also complete daily surveys, which include modified questions from the Pittsburgh Sleep Quality Index (PSQI), the Perceived Stress Scale (PSS), and the Kessler Psychological Distress Scale (K10). Once any correlations between environmental variables and overall wellness have been determined, it should be possible to use this technology to assess and predict one's wellness using environmental data.**

***Keywords*— Wellness Assessment, Bluetooth Low Energy, Mobile Application, Environmental Sensors, Internet of Things**

I. Introduction

The Canadian Mental Health Association reports that 50% of the Canadian population will have or have had a mental illness by age 40. Mental health is a growing concern among student populations, with suicide being the leading cause of death among Canadians aged 15-24 [1]. In 2011, the cost of mental illness in Canada was estimated at $42.3 billion [2]. This strain on the health care system indicates the importance of low-cost solutions for monitoring mental health.

The Internet of Things (IoT) is a network which enables the connection and interaction of devices around the world, with an expected 26 billion units by 2020 [3]. Wireless Sensor Networks (WSNs) are a key component of the IoT, with recent developments allowing the production of more low-cost, low-power devices [3].

This paper introduces a study aimed at implementing the IoT to assess individual wellness. The study assesses an individual's wellness with data retrieved from a smartphone-based system using mobile sensors. Student participants are asked to fill out a psychological survey thrice daily while in possession of a SensorTag, allowing for the acquisition of five environmental variables: ambient temperature, humidity, pressure, light, and activity. The participants connect to the application three times a day to complete the surveys. The purpose of the surveys is to assess the level of their overall mental wellness at the given time. The survey results in conjunction with the sensor data will allow for the determination and evaluation of any correlation between environmental conditions and individual wellness.

The framework presented is scalable, allowing for a large number and wide variety of subjects to participate. The scalability should also ensure that the experiment is replicable. Additionally, the system makes use of an Android application, which reads data from mobile sensors and sends results to a server for evaluation. It has also been designed to work specifically with the experiment's hardware components through Bluetooth Low Energy (BLE). The use of BLE was preferred over WiFi as it provides a low-power approach, allowing for continuous communication during the three data collection periods per day.

II. Related Works

Over the past decade, mobile sensors have been used in a variety of experimental methods to accurately assess an individual's wellness [4], [5], [6]. Each study uses a variety of environmental factors for which to collect data via wireless sensors.

In [4], data is used from wearable sensors and smartphone usage to draw correlations to academic performance, self-reported sleep quality, stress, and mental health. The study gave wearable sensors to 66 student participants over 30 days for a total of 1,980 days of data. Several surveys were completed by participants before beginning, including the Pittsburgh Sleep Quality Index (PSQI), the Perceived Stress Scale (PSS), and the Mental Health Composite Scale (MCS). The sensors included an accelerometer, photocell, actigraphy monitor, skin temperature sensor, and skin conductance sensor. Many associations were determined with PSQI groups related to sleep regularity, confirming a hypothesized relationship between high stress levels and low sleep quality.

A related branch of research is eHealth with a focus on physical health care. WSNs and mobile applications have been deployed in medical settings both practically and in research. In [5], the importance of personal health management systems is outlined along with the role they play in health care, and future opportunities. The paper highlights success in wrist-worn devices and biomedical clothes with textile electrodes that wirelessly communicate with medical centres. These devices are generally used to aid in diagnostics or monitor high-risk patients. Another application is to aid in at-home patient rehabilitation. At-home programs are preferable for the independence of patients and minimal cost. In [6], accelerometers are used for movement recognition and activity recognition. Movement recognition allows the physician to detect the state of the patient: idle, walking, running etc. Activity recognition can classify more specific movements

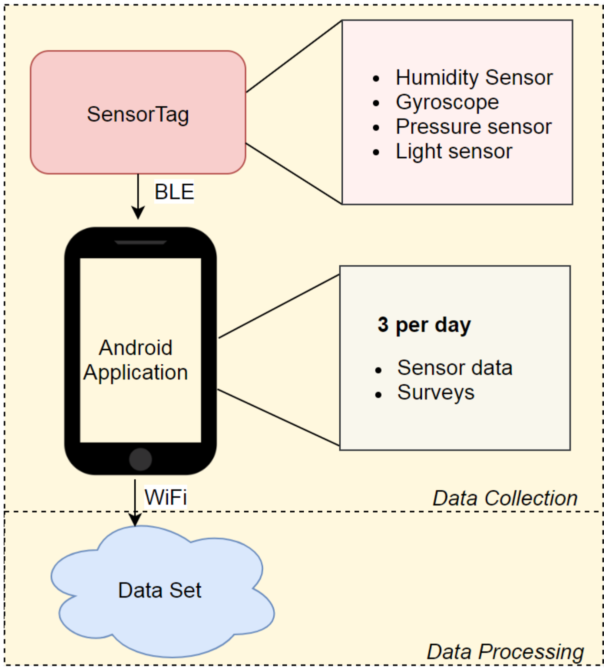


Fig. 1: Flowchart of the proposed model.

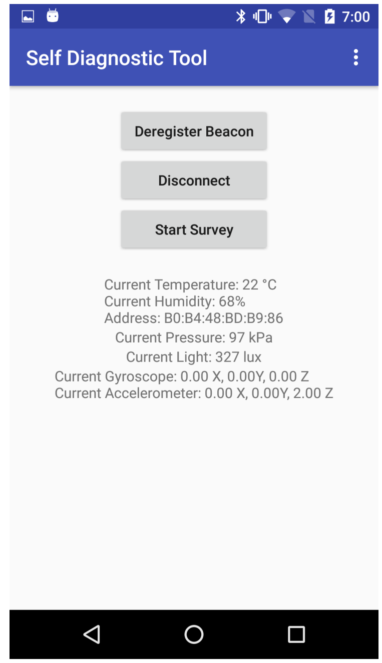


Fig. 2: Screenshot of the application's home screen.

required in physical rehabilitation including arm twists, arm circles, and shoulder rolls. They used smartphones as a reference platform and the onboard accelerometer. They achieved 91% accuracy in activity recognition cases and 99% accuracy in movement recognition cases. In addition to the works described in this section, the determination that these factors were worth investigating was in part due to previous University of Guelph research. In [7], [8], they describe a different framework drawing an initial correlation between wellness and environmental factors.

The system introduced in this paper focuses on collecting data from environmental sensors for comparison to the results of mental health-related surveys. The evident advantage of the proposed system is the focus on environmental factors retrieved from IoT devices. This effort should allow for identification and clear definitions of correlation for each of the five selected environmental factors. Furthermore, the system makes use of an Android application built specifically for this purpose. The application collects data from the sensors using BLE technology, including the results of the surveys, and sends them to a server for further processing.

III. System Framework

This section describes the system framework of acquiring data from participants. The User Interface (UI) is presented, as well as the method for retrieving sensor data, the psychiatric surveys proposed to be taken by participants, and the hardware components. A general diagram of the full system can be seen in Fig. 1, in which the four sensors on the SensorTag collect data to the Android application via BLE. Following this data collection period, the data is then sent to the data set via WiFi for further data processing.

A. Hardware

The SimpleLink Bluetooth low energy/ multi-standard SensorTag is an IoT kit in a small, portable package. It contains ten low-power microelectromechanical systems (MEMS) sensors, the data from which can be communicated to the cloud via BLE. The data is available online within minutes and is compatible with Android programming. The model used for this framework uses a CC2650 wireless microcontroller, which provides significantly low power consumption. The SensorTag and most of the included sensors are manufactured by Texas Instruments [9]. The following are the sensors used to collect data for the environmental variables: The HDC1000 humidity sensor, the OPT3001 Ambient Light Sensor, the BMP280 barometric pressure sensor, and the MPU-9250 MotionTracking Device. These sensors were selected from those available on the device due to their relevance to the acquisition of environmental data.

B. Mobile Application

The smartphone application was designed using the Android SDK. The purpose of the application is to log sensor data and survey results and forwards them to a server for further processing, data analysis and correlation.

The main screen, seen in Fig. 2, allows the user to register or deregister the address of the user's SensorTag. They can also connect or disconnect from a SensorTag once properly registered. Finally, pressing "Start Survey" begins one of the three daily survey sessions.

Figure 3 displays the screen that becomes visible at this point. The survey questions must all be answered to press "submit". During this time, the connected SensorTag is reading data for each of the environmental variables. Once the user

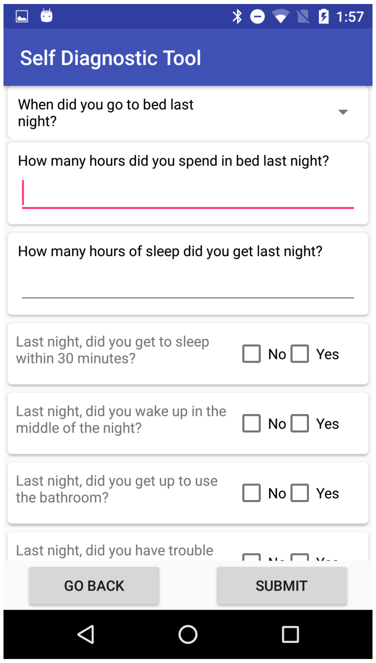


Fig. 3: Screenshot of submitting the psychological survey on the application.

connects to WiFi, the sensor data and related survey answers will be uploaded to the research server.

C. Data Acquisition

For the communication of data, the smartphone application acts as the client, while the SensorTag device acts as the server. Once the connection to the device has been enabled, the application specifies the services to which it wants access. In this case, the code requests access to the temperature, humidity, pressure, and activity.

The proposed placement for the SensorTag is on the participant's backpack. Since the participants in this survey will be students on the university campus, this placement ensures that the sensor will be taken with them throughout the day, always capable of sensing environmental conditions and movement. An alternative placement of on their person (ie. a belt loop) is available should the participant expect that their backpack will not be with them throughout the day. While the placement is left to the participant's preference, the importance of sensing movement without obstructing the capability of the other sensors is stressed.

The use of BLE is advantageous for this design due to its low power consumption, allowing for prolonged use of the SensorTag by the participants. IoT devices that communicate with BLE are used for relatively small data transfers, such as the data from the sensors available on the SensorTag.

D. Description of Selected Wellness Surveys

The research involves surveys assigned to the participants to be completed during three sessions each day. The application includes questions from the following three surveys: the PSQI, PSS, and the Kessler Psychological Distress Scale (K10). In our application, each survey was modified to inquire about current wellbeing, rather than long term.

The PSQI measures the quality and patterns of sleep in adults. The survey includes nine questions [10], which determine the duration of sleep and general wellbeing during this time.

The PSS is a psychological instrument for measuring the perception of stress. The PSS survey consists of ten questions [11] originally developed to measure the degree to which situations in one's life are appraised as stressful.

The K10 is a 10-item questionnaire used to determine psychological distress and to measure anxiety and depression [12]. Of note, the survey asks the participant whether they have felt nervous, depressed, worthless, or hopeless. It also asks about the participant's ability to complete work in relation to their emotions.

IV. Results and Signal Processing

A. Initial Testing

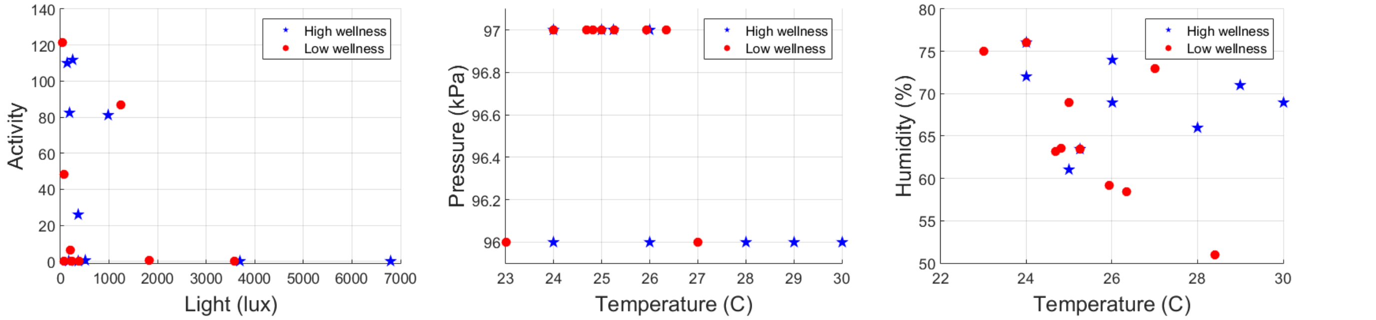
In the initial testing phase for the system, the application and SensorTags were given to six University of Guelph students with instructions to complete the survey several times a day, with a gap of several hours in between sessions. All data from surveys completed on campus were successfully sent to the server for evaluation. Each file received is mapped to the SensorTag's address and marked with the data completed and session number for that date. In total, data from 23 sessions has been retrieved. Three of these sessions have been omitted from current results as outliers due to evidence of malfunctioning sensors in the collected data.

Once received on the server, data is processed. The duration of time taken to complete the survey is measured in order to ensure that the participant read and answered the questions with due diligence. Currently, the average duration is approximately 2 minutes and 7 seconds. Any duration under one minute is omitted as an outlier as it indicates that the participant did not spend sufficient time to complete the survey thoughtfully. For non-outliers, the sensor data is processed by averaging the data points for temperature, pressure, humidity, and light. The activity is measured by calculating the standard deviation between gyroscope values.

For survey results, 11 questions regarding sleep are being evaluated, while 22 questions regarding general wellness are being evaluated. In each category, all questions are assigned equal weighting. The positive or negative responses to the questions are binary, allowing for a calculation of the average of positive responses in each of the two categories. Processed data from one session can be seen in Table I as an example.

B. Principal Component Analysis

Of the 20 sessions recorded in initial testing, the median of positive responses to survey questions was 80%. Ten scatter plots were generated in which each of the five variables was plotted against one another. Figure 4 shows a selection of these plots. To qualitatively analyze these preliminary results,



(a) (b) (c)

Fig. 4: Scatter plots showing results from 20 initial testing sessions.

TABLE I: Session results from Address ID 81.

Address ID 81	
Average temperature (°C)	25.25
Average pressure (kPa)	97
Average humidity (%)	63.44
Average light (lux)	373.1
Standard deviation in activity	0.0193
Survey responses	
Sleep-related inquiries (positive responses in %)	92
Well-being-related inquiries (positive responses in %)	70

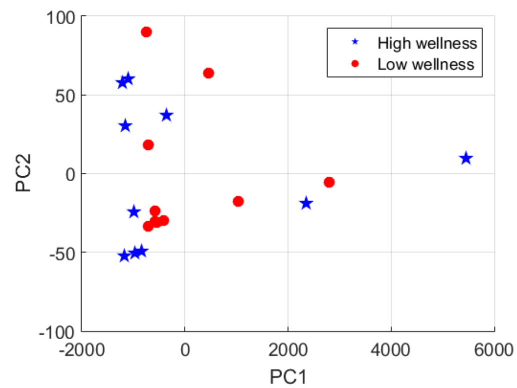


Fig. 5: Principal component analysis of the collected data.

the 20 sessions were split into two groups of ten: survey responses that indicate relatively positive wellness, and those that indicate relatively negative wellness. In the plots of Fig. 4 and Fig. 5, blue stars indicate the category of positive wellbeing, while red points indicate the negative category.

From these plots, several initial qualitative observations can be made in determining correlation between our environmental variables and overall wellbeing. Figure 4 shows three of these plots that clearly show separability and correlation. In Fig. 4a, there is an indication that participant movement is correlated with positive wellbeing. From Fig. 4b, it appears from that lower air pressure is associated with positive wellbeing, which is interesting as the readings of 96 kPa were observed on a rainy day. Furthermore, the temperature/humidity plot in Fig. 4c shows an association between days of heat and humidity and positive wellbeing. There is also a weaker correlation between brighter light and positive wellbeing, observed in Fig. 4a. The association of light, temperature, and humidity with wellbeing is expected in these summer months as these values indicate that the participant is outdoors.

Figure 5 shows a Principal Component Analysis (PCA) for the five environmental variables of the study where data is again separated in the two categories of high and low wellness. The PCA coefficients allow for the plotting of a great number of variables into two-dimensional space. This simplification of the system allows for visualized separability of our two categories of sessions. At this preliminary point in this study, the slight separability of our two categories in two-dimensional space provides confirmation that there is some degree of correlation between our five environmental variables and individual wellness.

V. Conclusion and Future Work

In this paper, a framework was proposed to assess one's overall wellness using environmental sensors. The proposed model had the study participants carry a portable SensorTag device for the duration of the experiment and made use of the SensorTag's sensors to collect five variables. The participants in this study were also be equipped with an Android application, which acted as the system's client, allowing the participant to complete a survey thrice daily and send sensor data to the server for that time period.

The initial testing phase of this study collected data and survey results from twenty sessions. From this data, qualitative correlations were observed between greater temperature, humidity, activity, light, and positive wellbeing. Additionally, data received on a day with lower air pressure showed some correlation with positive wellbeing. These initial results indicate that one's wellbeing improves with environmental conditions of the outdoors in warmer months. Future work will collect more data with varying conditions to attempt to confirm these correlations.

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