BioEssence: A Wearable Olfactory Display that Monitors Cardio-respiratory Information to Support Mental Wellbeing

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***Abstract*— This work introduces a novel wearable olfactory display that provides just-in-time release of scents based on the physiological state of the wearer. The device can release up to three scents and passively captures subtle chest vibrations associated with the beating of the heart and respiration through clothes. *BioEssence* is controlled via a custom-made smartphone app that allows the creation of physiological rules to trigger different scents (e.g., when the heart rate is above 80 beats per minute, release lavender scent). The device is wireless and lightweight, and it is designed to be used during daily life, clipped on clothes around the sternum area or used as a necklace. We provide a description of the design and implementation of the prototype and potential use cases in the context of mental wellbeing.**

Fig. 1. *BioEssence* is a wearable olfactory display that can be worn as a clip or as a necklace. The device can easily be attached to pockets, shirt necklines, jewelry threads, and cords.

I. INTRODUCTION

Hundreds of millions of people around the world suffer from different mental disorders. For instance, it is estimated that up to 33.7% of the population is affected by anxiety at some point during their lifetime, yielding costs of approximately 1 trillion USD per year to the global economy [1].

Some of the most common methods to treat mental disorders are Cognitive Behavioral Therapy or Psychoanalysis, which typically require a patient and a psychotherapist to meet in person for several sessions. However, many patients are reluctant to attend these sessions in person and/or share their private experiences with an unknown person. Due to these challenges, researchers have started to consider the use of pervasive smartphones and wearable devices to track physiology and support mental wellbeing.

A growing body of research considers the use of essential oils and fragrances to support mental wellbeing. For instance, several studies have shown that scents such as citrus, vanilla or lavender can help reduce anxiety and pain, as well as improve sleep and depression (e.g., [2], [3], [4], [5]). While the results are encouraging, these studies are mostly performed in laboratory settings which would still require the user to physically move and meet with the specialist. To help reduce this burden and extend the potential use of such systems in more naturalistic settings, this work presents *BioEssence*; a novel wearable device with the ability to trigger multiple scents based on the physiology of the wearer (see Figure 1).

II. RELATED WORK

A. Olfactory Displays

While there is a growing interest in the study of scents, most of the olfactory displays used in clinical laboratory studies are expensive, not portable, and too bulky to be used in real-life experiments. The most common methods to release scents in the laboratory involve using a nasal mask or a nasal cannula with tubes connected to a large olfactometer (e.g., [6], [4]). There are, however, few exceptions that have helped motivate this work. For instance, Kaye [7] explored the development of more automated scent-release mechanisms in the context of human-computer interaction. More recently, Dobbelstein et al. [8] developed a wearable olfactory display to augment mobile notifications. While their final form factor presents some similarities to our design (e.g., necklace form factor, multiple scents), their device does not consider the use of physiological sensing. Moreover, their method to release scent uses heat, while we rely on ultrasonic atomizers which are more commonly used for medical applications [9].

The work presented in this paper builds on top of an earlier exploration [10] [11] that provided a single scent and relied on external wearable devices to monitor physiological parameters. In contrast, *BioEssence* can deliver up to three scents simultaneously and provides a self-contained solution for physiological sensing. Therefore, the current form factor allows for a wider range of stimuli and comfortable monitoring of the physiology throughout the process.

B. Physiological Sensing

There exist a wide variety of methods and devices to monitor physiological signals. Some of the most widely used methods to capture vitals such as heart rate involve monitoring the electrical activity of the heart (i.e., electrocardiograms) or color changes of the skin (i.e., photoplethysmography). However, these methods require direct access to the skin which is not always readily available and can

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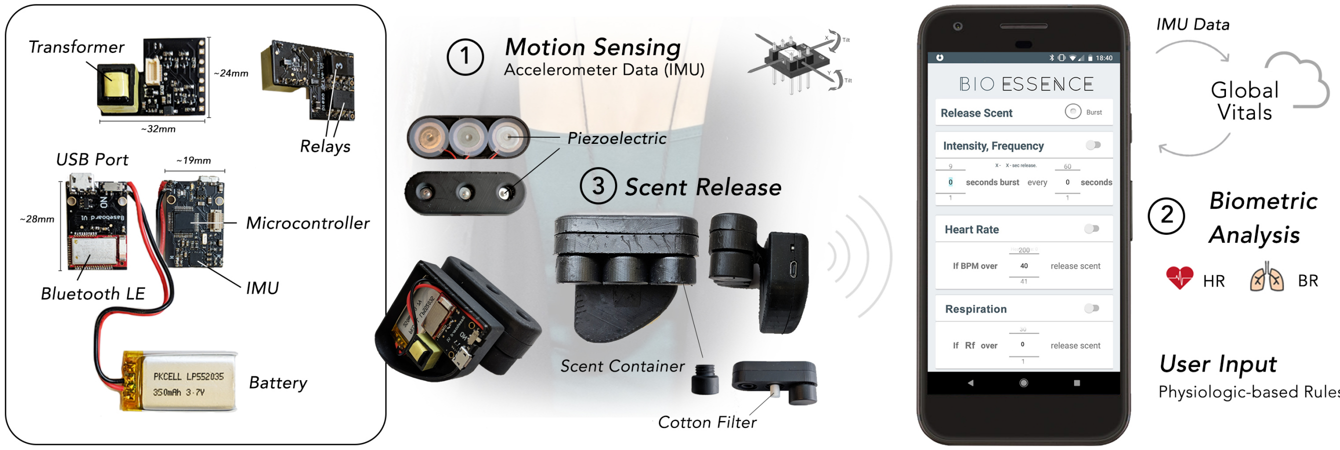

Fig. 2. Overview of the main components and flow of information: 1) the accelerometer inside *BioEssence* captures subtle chest vibrations and sends them to the smartphone application via Bluetooth Low Energy (BLE), 2) the information is sent to the cloud-based Global Vitals API which returns heart rate (HR) and breathing rate (BR) measurements, and 3) the application uses the physiological information and the user input to release scent accordingly.

be influenced by different factors (e.g., hair, tattoos). In addition, some of the sensing methods require the use of pre-gelled electrodes which may irritate the skin and may not be acceptable for certain populations (e.g., children, patients with burn injuries). A less invasive method involves monitoring subtle body vibrations associated with the beating of the heart and the movement of the blood (i.e., ballistocardiography and seismocardiography) [12]. This approach has recently gained more attention as it allows to monitor vitals passively and through clothes [13]. One method to monitor motion involves using wearable motion sensors such as accelerometers and gyroscopes which are pervasive in off-the-shelf devices (e.g., [14], [15]). Indeed, there have been some studies demonstrating the possibility of using motion sensors on the sternum to capture physiological signals (e.g., [16], [17]). Motivated by these studies, this work relies on an accelerometer contained inside the olfactory display to comfortably capture cardio-respiratory movements.

III. SYSTEM DESCRIPTION

The *BioEssence* wearable device consists of three main components: an olfactory display to provide scent stimuli, a physiological module to track the state of the wearer, and a smartphone application to coordinate the different components. Figure 2 shows an overview of the main modules and information flow.

A. Olfactory Display

The olfactory module was designed and 3D printed as a large tie-clip. The custom printed circuit board (PCB) was embedded into a 3D printed case that serves as a clip so the wearable can be easily carried in different ways around the sternum (see Figure 1).

The olfactory display module is composed of three containers (2 ml capacity/container) that are capable of releasing scent with any liquid that has a similar viscosity to a perfume or essential oil. Each container can release a scent via an encapsulated piezoelectric atomizer which vibrates at a high frequency and voltage (112 KHz, 147 Vpp) to transform the liquid into mist. We use a 10:1 transformer to amplify the voltage and turn DC to AC to power the piezos, and 2 relays to control them. We utilized a modular design with a piezo driver module stacking with the digital module (microcontroller, sensors, radio). *BioEssence* uses an ARM-based microcontroller (ATSAMD21G, Atmel) and a MDBT40 (Raytac) BLE module to communicate with the smartphone. The microcontroller is programmed using the Arduino development environment. The device uses a Lithium Ion Polymer Battery (3.7 V, 350 mAh) which allows for 6.5 hours of operation if a scent is released for 1 second every 20 seconds (i.e., 1170 releases) and BLE is constantly streaming sensor data. The weight of the module is 65.56 grams when the 3 containers are full and 59.29 grams when empty.

B. Physiological Sensing

We monitor the physiology of the wearer using an integrated 6-axis IMU (MPU6050, Invensense) that captures subtle chest vibrations. However, only the 3-axis accelerometer is used in the current prototype. The accelerometer data is read by the microcontroller at an average sampling rate of 60 Hz. To analyze the motion data, we use the Global Vitals API (Global Vitals LLC) which offers a cloud-based service with an improved version of the methods described in [14], [15]. Given a stream of motion data, the API provides heart rate and breathing rate in real-time in beats per minute and breaths per minute, respectively. In our work, we use 45-second streams with a sliding window of 5-seconds. The wearable has a battery life of 10 hours when constant physiological monitoring is streamed via BLE and no scent is released.

Figure 3 shows a graph example with heart rate and breathing rate measurements of a person working at the computer while wearing *BioEssence* as a necklace. For comparison, we show heart rate and breathing rate measurements obtained by an FDA-cleared ECG biosensor (BioPatch, Zephyr Inc),

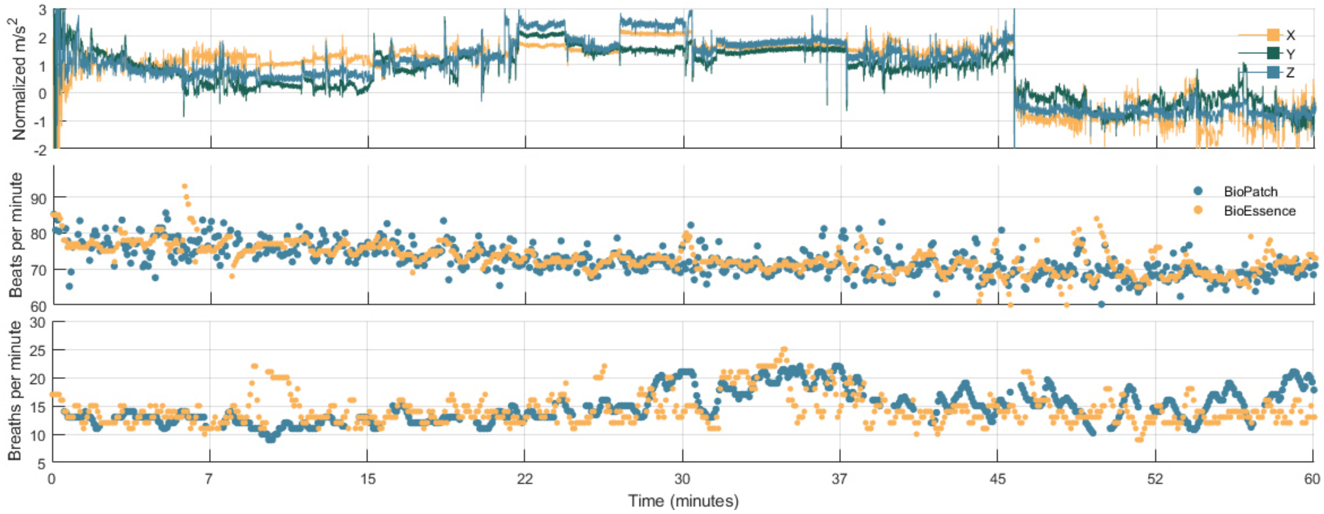

Fig. 3. Accelerometer (top), heart rate measurements (middle), and breathing rate measurements (bottom) of a person working at the computer while wearing *BioEssence*. Yellow circles indicate *BioEssence* measurements and blue circles indicate FDA-cleared ECG BioPatch measurements.

which uses pre-gelled sticky electrodes on the chest. As can be seen, the BioPatch and *BioEssence* are closely aligned. In particular, the mean absolute errors for this test sample are 2.73 beats per minute (STD: 2.72) and 2.59 breaths per minute (STD: 2.21). In relative terms, this corresponds to mean absolute percentage errors of 3.77% and 17.75% for heart rate and breathing rate, respectively. These results are encouraging and open new possibilities to comfortably pair cardio-respiratory information with wearable olfactory interventions. However, it is important to mention that motion-based physiological measurements would only work in semi-stationary environments in which subtle cardio-respiratory motions are not occluded by large body motions [18].

C. Smartphone Application

To coordinate the different modules, we created a custom smartphone application that uses BLE and runs on any Android device with an API Level 27. The application has several screens offering different options to the user. As a starting screen, the user can select to what *BioEssence* device s/he wants to pair the phone. Once the olfactory display is connected, the application activates the accelerometer and buffers all the measurements using UART communication. Once enough data have been collected, the information is sent over the Internet to the Global Vitals API which returns the physiological measurements in real-time. With a visual interface (see Figure 2), the user can define physiologically-based rules to trigger the release of scents. These rules are motivated by the IFTTT platform [19] and have the following syntax: *"if (A > B), then release scent C for D seconds every E seconds,"* where *A* is *heart rate* or *breathing rate*, *B* can take any value from 40 to 200 beats per minute or from 0 to 40 breaths per minute, *C* can take any value from 1 to 3 indicating the containers, *D* can take any value from 0 to 9 seconds, and *E* can take any value from 1 to 60 seconds. The current rules are manually added by the user but future versions will explore creating automated ones that learn over time based on the physiological baselines of the users.

IV. APPLICATIONS

Due to the wearable form factor, *BioEssence* facilitates real-life just-in-time olfactory interventions that consider the physiology of the user. This section describes some of the main mental wellbeing applications.

A. Stress and Anxiety

Odors modulate emotion and cognition and have been successfully used to treat certain psychological problems such as stress or anxiety [20]. Lavender scent has been one of the most commonly used fragrances to reduce anxiety at the dentist [21] or during test taking [22]. As stress and anxiety tend to increase both heart rate and breathing rate, *BioEssence* offers the possibility of automatically detecting relevant episodes and triggering scents when most needed.

B. Depression

Some studies have shown the possibility of using essential oils such as citrus fragrance [3] or rose scent [23] to relief depressive symptoms. Interestingly, there is some work suggesting how sweet-smells could be used to treat depression by "fooling" the brain glucose level sensors [24]. As in previous cases, *BioEssence* could facilitate the study of these effects in real-life and be used to provide more frequent interventions which are needed to achieve a long-lasting effect.

C. Pain

Several studies have shown that odors can influence the perception of pain. For instance, Prescott and Wilkie [25] performed a study in which participants wore a mask covering the nose and mouth with different types of scents, and showed that those with sweet-smelling characteristics increased pain tolerance. Another study used lavender scent to significantly decrease women's pain when giving birth [26] by manually rubbing their hands to let them inhale the essential oil. In addition of tracking relevant physiological parameters, *BioEssence* would enable a more passive scent delivery method that would be more appropriate when undergoing pain episodes.

D. Sleep

Several studies have explored the use of scent to help induce sleep due to its potential calming effects. For instance, Field et al. [27] used lavender to help improve the quality of sleep. In a separate study, Schredl et al. [28] demonstrated that certain smells can also be used to influence the emotional valence of dreams. In particular, they showed that the scent of roses during sleep yielded more positive dreams, while the scent of rotten eggs (H2S) resulted in negative ones. In this case, researchers used a 60 cm tube to connect the nose to a stationary olfactometer. As in the other scenarios, *BioEssence* could offer a more comfortable solution that is less likely to disrupt the person while sleeping. In addition, the on-board accelerometer could be used to track other parameters such as sleep stages [29].

V. CONCLUSIONS

This work describes *BioEssence*; a novel wearable olfactory display that can track heart and breathing rate passively and through clothes. The user can customize physiologically-based rules to automatically trigger scent release during daily life using a smartphone application. In addition, the physiological data can be used to track the effect of the olfactory interventions which facilitates a close-loop system that adapts to the user over time. Our immediate future efforts will be focused on real-life deployments and open-sourcing[1] the platform to researchers and hospitals. We hope that in the future, devices like *BioEssence* can be used as a complementary method to treat anxiety, stress or sleep disorders and increase pain tolerance.

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