An RFID Based Localization and Mental Stress Recognition System Using Wearable Sensors

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Abstract: A vast increase in the percentage of elderly people over the past few decades has induced a serious concern among the research fraternity worldwide. Consequently, the large increase in the number of elderly needing assistance because of chronic diseases is expected to take place. Dementia, depression and mental stress are among the most disabling diseases with dangerous consequences such as wandering into hazardous or insecure areas. This wandering, particularly in urban areas can be life threatening. Recently, with the rapid emergence of disruptive technologies like Internet of Things (IoT), Radio Frequency Identification (RFID) and wireless bio sensors, it has become feasible to build systems that combine IoT and the cloud for monitoring the elderly suffering from dementia or depression. Furthermore, mental chronic diseases, such as stress and depression, are becoming a major concern for governments around the globe. The American Psychological Association (APA) categorizes stress, anxiety and depression as main factors for diverse mental health problems. The cost for treating work-related stress, anxiety and depression, is estimated to be around 617 billion euros per year in Europe alone. Wearable devices for monitoring chronic diseases such as mental stress and depression have been considered as game-changers to the way diseases are managed, by measuring vital signs like skin conductance and changes in the levels of biological stress, and sending warnings remotely to an online server. This paper proposes a work in progress Arduino based real-time stress recognition and localization system using wearable RFID and vital sign sensors for elderly suffering from Dementia and mental stress. The current work utilizes the heart rate variability and Electro Dermal Activity wearable sensors based on the Bitalino development system for measuring mental stress and anxiety in a smart home setting for elderly living alone by exposing a number of subjects to stress and anxiety stimulating horror videos. The system was tested successfully in the university lab.

1 INTRODUCTION

Stress is a common human physiological and physical body reaction. However, prolonged stress may lead to adverse effects on human health. One of the victims of prolonged stress are employees at the workplace office. Stressed employees are often unproductive, and companies must bear their healthcare costs. Emotionally stressful and traumatic events damage the human psyche. According to new research, stress may damage the heart as well. In the most relevant study so far on this topic, scientists estimate that a stress-related psychiatric disorder may increase the rate of heart attacks by 34%, strokes by 75%, and high blood pressure by over 100%. A stressful encounter or event increases the risk of heart attack by a factor of 1.34, stroke by a factor of 1.75 and high blood pressure by a factor of 2.15. Even though stress-related disorders are treatable, it is important to diagnose the symptoms of stress early through regular monitoring of the human body. The goal of this project is to develop an effective stress monitoring system for office employees and thereby prevent the onset of stress-related health

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disorders (Bacon, 2019).

Stress is considered as the health epidemic of the 21st century according to World Health Organization (WHO). The WHO defined the stress as a response of a mismatch between the pressures and demands in life with their abilities and knowledge. In fact, the stress has the impact in not only the emotional and physical health of human but also businesses (Fink, 2016). In 1999, stress costs European Union 20 billion euros where 50% to 60% of all sick days and 42 billion dollars for USA in 2002 (Brun,). Furthermore, according to Richmond Hypnosis Center, 110 million people die every year due to stress. That means, every 2 seconds, 7 people die. According to WebMD, intense and long-term anger causes mental health problems including anxiety, depression, self-harm, high blood pressure, coronary heart disease, stroke, and cancer. Heart rate variability (HRV), referring to the tiny variation of the interval between successive sinus heartbeats, contains abundant information of autonomic nervous response (Malik et al., 1996; Kim et al., 2006).

HRV can reflect the balance between sympathetic and parasympathetic branches of the individual autonomic nervous system by its spectral analysis. Time-domain, frequency-domain and nonlinear indices of HRV have been widely used as the marked features for emotion recognition.

Kim et al. used time-domain and frequency-domain HRV indices to achieve an accuracy of 61.8% for classifying sadness, stress, surprise and anger emotions (Kim et al., 2006). Mikuckas et al. developed a human-computer system for stressful state recognition by analyzing multiple HRV indices from time-domain, frequency-domain and nonlinear and reported that most HRV indices were sensitive to stress state (Mikuckas et al., 2014).

Furthermore, Dementia is considered to be a chronic disease, where the elderly suffers from a deterioration in cognitive functions (i.e. the ability to process thought) beyond what might be expected from normal younger people. This disease affects memory, orientation, thinking, comprehension, learning capacity, judgement, and consciousness. The impairment of the cognitive function is usually accompanied, and occasionally preceded, by deterioration in emotional control, social behavior, or motivation. The impact of dementia on family, caregivers and society at large can be multi-dimensional: physical, social, psychological, and economic (Raad et al., 2021).

Lately, researchers have focused on the importance of quality of life in a healthcare setting. The quality of life (QoL) is defined as the need to be able to carry activities of daily living (ADL) independently, enjoy time, and feel empowered (EDA, 2021). The World Health Organization (WHO) defines QoL as “the individual’s recognition of their position in life in the context of the culture and value systems in which they live and related to their goals and concerns”. Providing the elderly with smart-home services like localization is in the right direction for boosting their QoL (Raad et al., 2021).

These related studies gave us a good basis for further exploring the changes in HRV indices between different emotional states. This research aims at developing a comprehensive system based on disruptive technologies like RFID & wearable biosensors for real time monitoring of mental stress, depression and wandering detection of elderly. The relevance of proposed research is particularly in the valuable contribution to the research area of Internet of things, battery less RFID and wireless biosensor for monitoring mental stress and localization of elderly suffering from Dementia in a smart home setting. Here, we propose an affordable prototype of a novel real time stress recognition system using wearable vital sign sensors. The proposed system constitutes an excellent work in progress test bed for establishing an optimal telehealth biosensor network for stress level identification, acquisition of vital signs data using biosensors with wireless capabilities.

The paper is organized as follows. Section 2 describes the research methodology including the physiological and physical basis of the research as well as technological basis of the research. Section 3 introduces the proposed RFID based tracking system. The paper ends with discussion on the future research and the privacy and security related issues.

2 RESEARCH METHODOLOGY

This section describes the research methodology including the physiological and physical basis of the research as well as technological basis of the research.

2.1 Electro Dermal Activity (EDA) and Stress

The human heart provides vast insight into our human body. One such term is HRV which measures the variation in time between two consecutive heartbeats. HRV is affected by a variety of physiological phenomena such as breathing, hormonal reactions, metabolism, movement of the human body and one of the factors are stress reactions and emotional reactions. In an ideal scenario, HRV of a person increases during relaxing activities such as meditation, when a person is in a good mood, etc., while during a stressful encounter, HRV decreases which point to an inverse correlation between HRV and stress (Hoffman,). Fig.1 illustrates the HRV characteristics under high stress and low-stress conditions measured using volunteering students subjects during exam period.

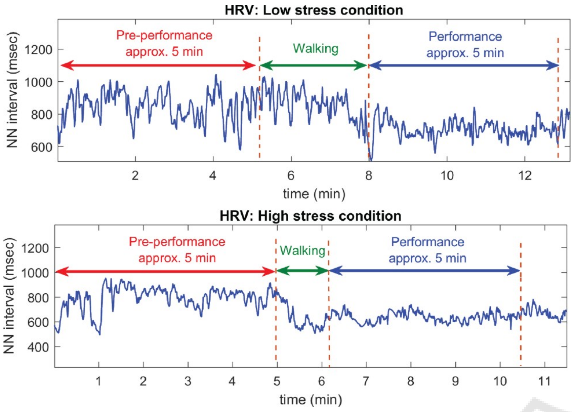

Figure 1: NN interval in a low and high stress situation.

Electro dermal Activity also known as galvanic skin reflects the activity of the sympathetic nervous system. The state of the sweat glands reflects the measure of skin resistance. When the sympathetic nervous system is activated, the sweating of the skin increases the conductance of the skin. During activation of the sympathetic nervous system due to stressful encounters, the brain sends a signal to the skin to increase the sweat levels. When the sweat level increases, the corresponding increase in skin conductance can be measured to study the stress levels. Skin conductance can be characterized into two types:

1. Tonic skin conductance response which measures smooth and slow-changing conductance levels and
2. Phasic skin conductance response which measures the rapid changing peaks.

The skin conductance level using tonic skin conductance and phasic skin conductance response tests, conducted in Yi Yang and Bingkun Yang's work in Human Computer Interaction Lab (EDA, 2021).

2.2 The System Hardware

The proposed system is implemented in the form of a prototype of Arduino microcontroller interfaced to a multitude of bio sensors from Bitalino kit using the bio signal platform. The Arduino is an open-source platform for microcontrollers that are used by communities and non-engineering people to help in building innovative thinking and encourage communities to develop new electronic products that help in many ways such as manufacturing and other sectors. The Arduino UNO utilized in the proposed stress-monitoring system is interfaced to Gravity heart rate sensor (a thumb-sized heart rate monitor designed for Arduino microcontrollers). It has a Gravity interface, for easy plug-and-play connectivity. It is a pulse sensor that is developed based on PPG (Photo Plethysmography) techniques. It is a simple and low-cost optical technique that can be used to detect blood volume changes in the microvascular bed of tissues (see Fig.2).

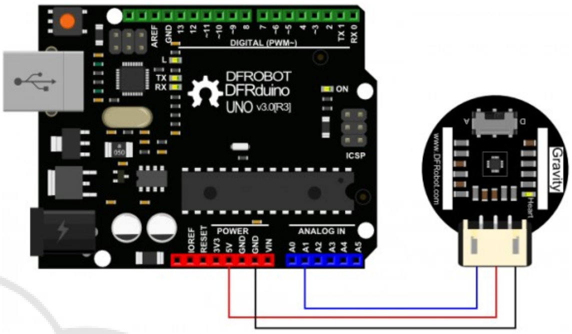

Figure 2: Interfacing Gravity heart rate sensor with Arduino Uno.

BITtalino is a hardware and software toolkit that is designed to measure body signals. It could be used for biomedical proposes or industrial applications for the welfare of workers who work in a harsh environment and it can help in designing new wearable products for everyday use. The BITalino hardware has a microprocessor with an external battery and has 32kB flash program memory; 1kB EEPROM; 2kB internal SRAM, operating voltage 3.3V-5V, it can be connected via Bluetooth or USB port. The BiTalino was utilized using the Biosignal platform to lay the ground for developing an IoT based wearable stress monitoring system.

The testing took place utilizing volunteering students in the final year project examination period, where the students suffer from a lot of mental stress. The measurement of mental stress took place using wearable heart rate, EDA & ECG wearable sensors from Bitalino kit using the Biosignal platform. We have performed extensive experiments using student volunteers in the university RFİD lab due difficulties we encountered to access elderly patients in hospitals.

2.3 The Heart Rate Measurement

The four graphs below illustrate the Heart rate measurement and HRV before and during stressful situations, graphically depicted in Figures 3-6.

Figures 3 and 4 display the heart rate and the corresponding HRV readings of the student when he is at rest.

Figures 5 and 6 display the heart rate and HRV at the time of the stressful encounter. When the subject experiences a stressful moment his heart rate spikes and HRV remains low with little to no variation between successive heartbeats.

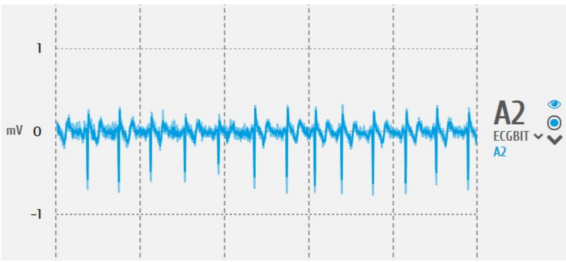

Figure 3: Heart rate before the moment of stress.

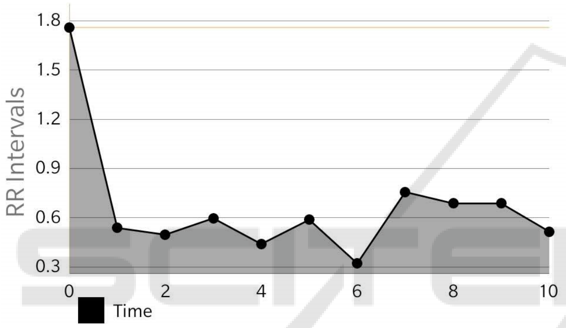

Figure 4: Heart rate variability before moment of stress.

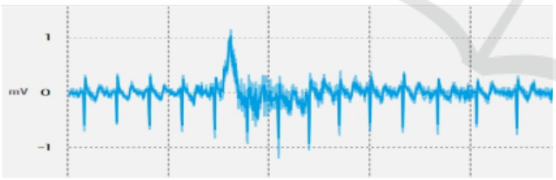

Figure 5: Heart rate measured at the moment of stress.

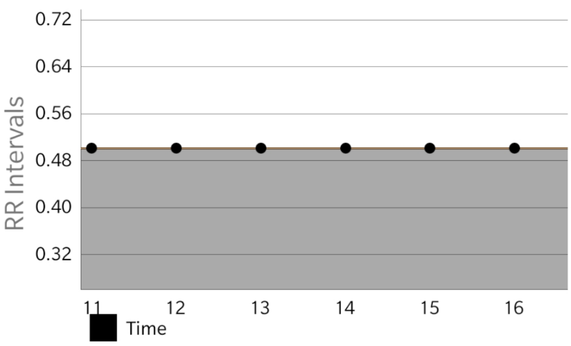

Figure 6: HRV measured at the moment of stress.

2.4 Stress Measurement Using EDA

Figures 7 and 8 illustrate the tonic skin conductance level from BITalino software before and after the stressful encounter invoked by a horror video. The skin conductance displayed constant low skin conductance level in Fig.7 and then displayed a huge spike in Fig.8 indicating a moment of stress.

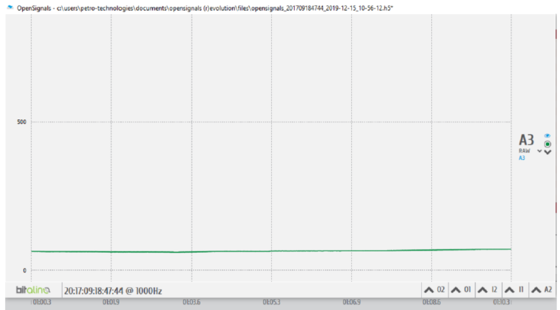

Figure 7: Tonic skin conductance in a relaxation scenario.

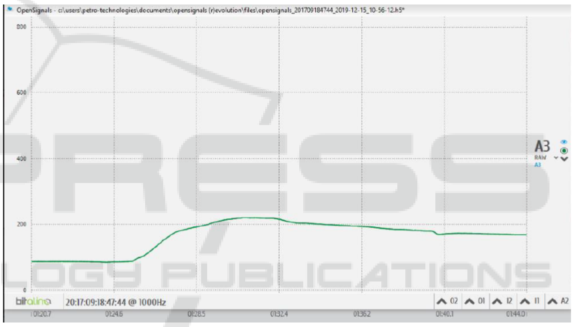

Figure 8: Tonic skin conductance at the moment of stress.

3 THE PROPOSED RFID BASED TRACKING SYSTEM

Elderly suffering from dementia and other chronic diseases who are living alone at home, are usually too frail and not able to carry basics activities of daily living (ADL). Also, elderly suffering from dementia often show psychotic behavior and instance of complete unawareness, which requires continuous assistance and support. Living in smart homes eases the situation of these people by providing necessary facilities and services to make their lives more enjoyable. One important aspect of smart homes is the availability of a seamless localization system. The main feature of such systems is to be able to track remotely the movement of the elderly at the room level. Currently, this is done using surveillance tracking systems such as cameras. Although these systems have been successful, they are privacy invasive. In this work, we are proposing to use a Sirit RFID robust reader, commonly used in industrial applications to track the movement of the elderly. For our design, the reader is configured to read and identify tags in the range of the deployed antennas. The reader is connected to linearly polarized antennas with RF power of 30 dbm. We used antennas with coverage range of 7 to 15 meters.

3.1 RFID Sensor Platform

The passive RFID tags are used to find the location of the elderly. Therefore, each elderly is to wear a personal tag all the time. The tag can be attached in different places on the body as illustrated by Fig.9. The localization principal is based on three possible zones: within bedroom, outside bedroom, while exiting the house. The methodology of the proposed solution is based on distributing four antennas: three in the house (one antenna in each room) and one at the exit. To detect that the elderly person is inside their room, he needs to be detected by the room antenna. The role of the exit antenna is to trigger that the elderly is tending to wander outside the house. Time represents the last timestamp at which the readings took place, they refresh in real-time (see Table1 for the timestamp of the elderly localization indoors). See Fig.10 for the localization algorithm of the elderly roaming inside and outside the house (Raad et al., 2021).

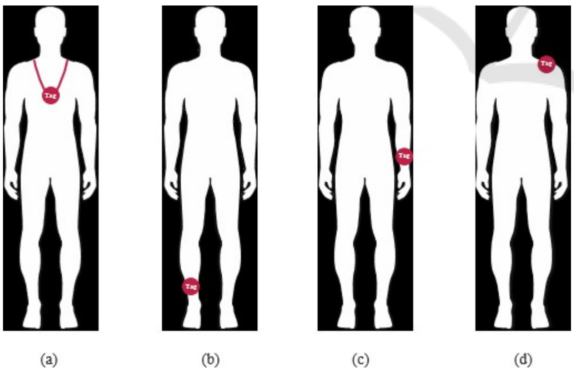

Figure 9: Tonic skin conductance at the moment of stress.

Table 1: Localization of elderly with timestamp (Raad et al., 2021).

Id	Location	Time
0X00A1	In House	11:44:29
0X00A2	Roaming outside House	11:44:01
0X00A3	Inside Room	11:44:38

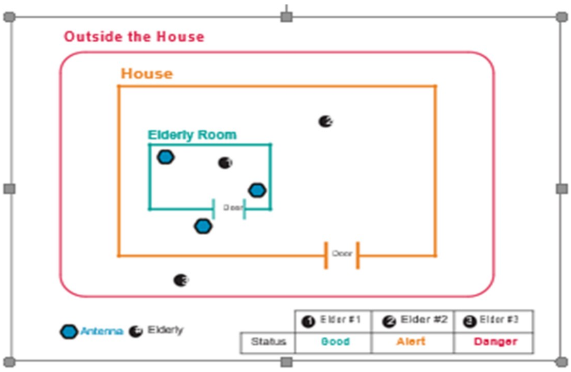

Figure 10: Higher level Localization of the Elderly (Raad et al., 2021).

4 DISCUSSION AND CONCLUSION

We carried several tests to determine the best performance of the antennas to detect the wearable RFID tags. The testing in the lab started by adjusting the antennas based on their polarization to maximize the reading probability of the tags inside and outside the lab environment.

The proposed RFID localization system was tested successfully using three volunteers. The RFID part of the research contributes an added value for boosting the quality of life by mitigating the number of falls for elderly suffering from Dementia, and by constituting a robust telehealth smart system for sending warnings in the onset of elderly wandering outside their home.

In addition to that, in the context of elderly suffering from depression and mental stress, Physiological and bio signals such as galvanic skin response, electrocardiogram (ECG), photo plethysmography (PPG), electromyography (EMG) and electrical impedance spectroscopy (EIS) can provide reliable information regarding the intensity of stress level.

The relevant stress data collected constitutes the first phase of this research to investigate the feasibility of implanting such a system in a non-invasive form. In this direction, the intended research in the near future aims to investigate sensors' placement within the human body, which will help to develop an optimization configuration of vital sign sensors network for stress level detection. In order to generate stress, a set of different audios and videos will be used by referring to the World Health Organization (WHO) and specialists in the psychotherapist fields. The videos and audios will be selected to specifically generate several types of mental stress including neutral, mild, moderate and severe stress levels. A study on existing affective frameworks used for a similar purpose will be deeply carried out. In addition, to mimic reality and improve the efficiency of the generated stress, a full virtual reality system with all accessories will be used with the selected contents. Data collection and preprocessing will be carried out and various machine learning algorithms will be investigated through extensive simulation for stress level classification. See Fig.11 depicting the scenario of investigating the optimum placement of the various wearable mental stress monitoring sensors on the human body. The future work will be centered around an IOT telehealth system for monitoring the human mental stress to mitigate the drastic effect of stress on the quality of life, and utilizing RFID for immediate localization of elderly once the warnings are received by a caregiver.

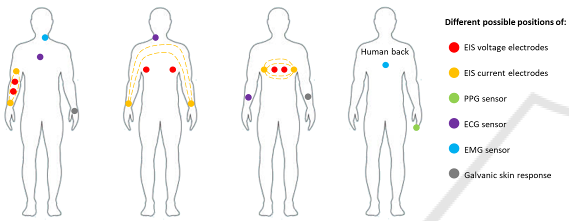

Figure 11: Optimum placement of the wearable mental stress sensors.

Finally it should be noticed that the 21st century has brought with it a higher risk of attacks on medical devices and medical applications, the emergence of new types of such attacks and, accordingly, an enhanced risk for patients, what use wearable, wireless or embedded medical devices and may suffer from the malicious actions of such intruders: medical data nowadays is more valuable and attractive for attackers than financial data (Burky, 2022; Doynikova et al., 2022).

In regard with the elderly, suffering from dementia and other diseases mentioned in this article, the risk blast off even more: using the devices of more vulnerable patients, attackers can access the data of medical institutions, relatives of such patients, directly harm the elders.

Recent studies have shown that there are countless attack vectors, attack methodologies and vulnerabilities of the medical devices of all types (Yaqoob et al., 2019). The security and safety of medical devices are vital for people using any kind of medical device, including implantable medical devices (IMDs). It is possible that IMDs will also be subject to complex cyberattacks – ransomware attacks – over time. At the moment, the most urgent problem seems to be breaking such IMDs by simply studying the specifications and documentation for them, which are freely available on Google, as well as by breaking the cryptographic protection (Radcliffe, 2011). Lee et al. (Li et al., 2011) researched insulin pump systems. They managed not only to get encrypted information from the device, but also to fake false glucose readings on the monitor. In addition, they successfully sent their own commands to the pump due to the lack of authentication. Radcliffe (Radcliffe, 2011) and Takahashi (Takahashi, 2011) have shown that they can take full control of some insulin pump systems because these medical devices receive unauthorized radio signals or commands. That is why these and other researchers are not only hacking medical devices, but also working on security solutions such as passwords for pacemakers and other embedded medical devices (Storm, 2011).

Another example of a wearable device that may attract the attention of hackers is Nymi, a small wearable device that uses an electrocardiogram (ECG) to authenticate the user (D'Souza,). According to the developers of this device, a person's own heartbeat is a unique key that can be used to unlock any paired device. If the device is hacked, then with the help of persistent identification, one can access any other devices that belong to a person: a car, preferences, location, and downloaded data. Manipulating a medical devices of people with mental chronic diseases may cause severe damage and unpredictable outcomes. This is why it is so significant to take a security and privacy of the medical devices into consideration within the whole period of medical device existence (starting from design and till utilization).

The new system developed by the authors of this article is based on Radio Frequency Identification (RFID) technology, which many authors consider revolutionary and versatile: RFID can be used both in the provision of direct medical services, the provision of the services related to medical purposes, and directly to track patients (Bochem et al., 2022; Abugabah et al., 2020; Rajak and Shaw, 2021). It should be noted that despite the increased and ever-increasing risk for the security and privacy of medical devices, manufacturers of the latter still pay less attention to safety issues, giving priority to the efficiency and performance of devices (Doynikova et al., 2022). The RFID-based tracking system proposed in this article, in addition to efficiency, also will take into account issues of privacy and security.

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