SolicitudeSavvy: An IoT-based edge intelligent framework for monitoring anxiety in real-time

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***Abstract*—Anxiety disorders affect more than 18 percent of the population and is the most common mental illnesses in the US. There is a great demand to address this emerging epidemic with tools to differentiate and diagnose such disorders, and to create awareness especially in places like NorthEast Texas which is home to 1.5 million people with 58 percent of them living in rural areas. The goal of the proposed device is to diagnose as many anxiety disorders as possible, in real-time using the diagnosing wearable framework, SolicitudeSavvy, which uses technology such as the Internet of Things (IoT), a network of interconnected devices, to accomplish such a task. The proposed IoT-based device has two components: a custom-built wearable necklace that contains sensors to collect data about the user as they go about their day and a low-cost portable system that monitors Electrooculography (EoG) signal using a camera. The partial necklace attaches to the shirt and opens halfway around the wearer's neck and the EoG can be attached to any eyewear. The device monitors the user throughout the day, and even as they go to bed at night. This information is accumulated in the IoT cloud and analyzed to see exactly what type of disorder(s) the patient may suffer from. The authorized personnel i.e. doctor or therapist, can use this pattern to find a treatment that best suits them and is most likely to resolve their affliction.**

***Index terms*—** Internet of Things (IoT), Smart Healthcare, Electrooculography, Immersive environment, Augmented Reality

I. Introduction

As the levels of anxiety become more disproportionate in a person, it can lead to a medical disorder called anxiety disorder. Long-term anxiety can have a deleterious effect on central nervous system which in turn might lead to headaches, dizziness, and depression. Per the reports of Anxiety and Depression Association of America, anxiety disorders are the most common illness in the U.S., which affects 40 million adults or 18.1 percent of the population every year and only about 36.9 percent of that population receives treatment. Anxiety disorders affect more than 18 percent of the population and is the most common mental illnesses in the US. There is a great demand to address this emerging epidemic with tools to differentiate and diagnose such disorders, and to create awareness especially in places like NorthEast Texas which is home to 1.5 million people with 58 percent of them living in rural areas. The main challenge is in diagnosing a specific anxiety disorder based on general symptoms as each of them have varying effects on a person's physiological health. Furthermore, due to a need to identify a pattern in the symptoms, it is vital to develop a continuously monitoring wearable which can assist doctors during the traditional appointments. With growing research drive to improve mental health outcomes, especially among young adults, the research focus is more on developing light-weight wearables which can be used for monitoring anxiety in real-time. Currently, most of the existing frameworks and corresponding data analysis for anxiety monitoring, are applicable only in a closed clinical setting.

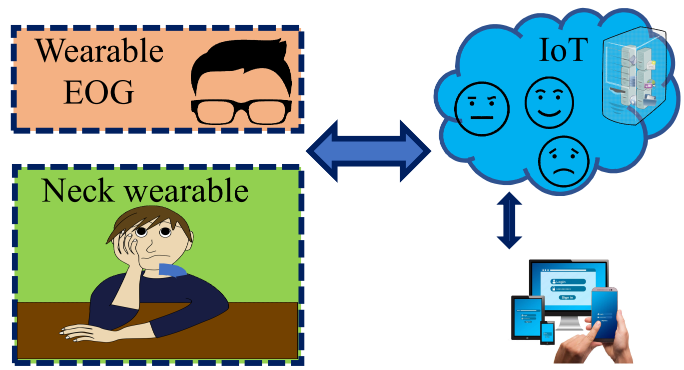


Fig. 1. Conceptual Overview of the proposed SolicitudeSavvy Framework

The Internet of Things (IoT) is a network of interconnected devices that helps in acquiring data from simple sensors to the cloud through wireless protocols [22] . The goal of this research is to develop a wearable EOG system along with a necklace wearable that can run the machine learning algorithms to detect anxiety in real-time based on the eye movements and physiological signals. The proposed system, SolicitudeSavvy, is validated with help of a camera attached to a single board computer, that helps in locating the eye position and movements and a microcontroller-based necklace for monitoring the physiological signals. The proposed system can be worn as any other eyewear and can be extended for applications related to positioning eye movements in medical ophthalmology, operator focus analysis, special education development based on augmented and virtual reality frameworks. Figure 1 shows the conceptual overview of the proposed real-time anxiety monitoring framework.

The organization of this paper is as follows: The novel contributions of this paper are described in Section II. A broader perspective of the proposed SolicitudeSavvy framework for monitoring anxiety in real-time is presented in III. Some literature on existing research work on modeling anxiety monitoring frameworks and applications of EoG is discussed in Section IV. An overview of the system-level modeling of the proposed framework is given in V. The implementation of the designed blocks along with simulation results are discussed in VI.

II. Novel Contribution

The following are the main contributions of this research:

- A novel real-time wearable electrooculography (EoG) is designed with help of single board computer.
- A necklace type of wearable for monitoring the anxiety through physiological signals of the user is designed.
- The proposed framework is edge-intelligent and has very little dependency on the IoT cloud.
- The proposed framework for detecting anxiety using wearable computing is validated in real-time with help of FDA approved wearable.

III. SolicitudeSavvy for real-time anxiety monitoring: A Broad Perspective

Electrooculography (EOG) which is the measure of electrical potential between electrodes placed around the eye, has many key implementations in both biomedical and electronic industries. Device control using head and eye movement can be used to enable sufferers of motor function disabilities allowing for control of wheelchairs or prosthetics and navigation of Graphical user interfaces. Home automation using the gaze-based determination of focus and eye-based gestures would allow existing home systems to be controlled with as little as a stare and a wink. POV control allows Ophthalmology is a medical field that concerns itself with eye disorders, EOG readings have been used for the detection of neuropathies and numerous hereditary muscular degenerative diseases, most notably Best's Disease. The use of EOG monitoring systems have extended to psychological studies such attempting to diagnose disorders such as Attention hyper deposit disorder. In Engineering EOG can be used and a complimentary control vector for Point of view (POV) applications. Utilizing eye movement to control a camera on an autonomous unit can allow more precise fluid control for autonomous drones, medical robots and in emergence response proxies.

Another part of the proposed framework is the partial necklace that helps in monitoring the anxiety levels through the daily activity of the person and the amount they interact with others. This mainly helps in detecting anxiety induced due to social environment or seasonal changes. By monitoring these features, the goal of this research is to find a correlation between state and trait anxiety in real-time through the IoT-based framework.

IV. Related Prior Research

With help of wearable computing systems, various healthcare applications such as daily activity monitoring [1] , food intake monitoring [2] , women's health monitoring [3], emergency routing to first responders [24] and so on can be achieved.The negative behavioral and psychological sympotoms (NBPS) due to anxiety and agitation has been monitored with the help of a portable device in [4]. In [5], a gaming approach based anxiety monitoring framework is discussed. Wen et al. have discussed a real-time anxiety evaluation system in [6]. A real-time anxiety monitoring framework using single-board computer is proposed in [25]. Similar to this, a stress monitoring system during pregnancy using the heart rate variability sensors is discussed in [7]. With use of technology such as smart-shirt and smart bracelet, a stress and anxiety estimation system is proposed in [8]. Anxiety induced in children due to the change in temperature and humidity is discussed in [23]. In [9], the heart rate variability based stress and anxiety monitoring system in post-traumatic stress disorder (PTSD) is discussed. The physiological changes related to anxiety in children is studied in [10]. Anxiety in specific cases such as during travel [11], classroom setting [12] , suicidal ideation monitoring [13] , substance abuse detection [14] , have also been studied.

In emotion recognition using augmented reality frameworks, electrooculography (EOG) plays a very important role [15]. In [16], a 8-channel EoG for analyzing the depth of the eye movement is discussed. A computer-based design for tracking eye movement in EoG is proposed in [17]. EOG also has its applications in detecting motor neuron disease such as Amyotrophic Lateral Sclerosis (ALS) [18]. Other applications including monitoring activities such as eye movement while using computer [19], reading activity [20], motor movements in wheelchair [21].

V. System level modeling of SolicitudeSavvy framework

A. Features for monitoring anxiety

In the proposed framework the key features considered for anxiety monitoring in real-time were eye-event tracking, daily activity and the amount of times a person interacted with others. Eyes are a very powerful and useful communication tools that contributes significantly to analyze the emotion in a person. Features related to eye-event tracking include where the person is looking (eye gaze), motion of an eye relative to the head and the number of times the eyelid is closed are all possible combinations related to research in deploying eye activity. In this research we used wearable EOG system for real-time eye-event tracking.

A person's lifestyle can be regarded as healthy based on how active he or she stays. If a person has moderate exercises for atleast 3 to 5 days a week, it can be regarded as healthy lifestyle. The daily activity of the person can be monitored using the data collected through accelerometer.

In the proposed framework, in addition to monitoring the daily activity of the person, their interaction with others is monitored. This is mainly to differentiate between induced anxiety, i.e. trait anxiety and state anxiety.

B. *Proposed neck wearable for monitoring anxiety*

Figure 2 shows the proposed wearable designed as a neck wearable for monitoring the anxiety. This neck wearable is mainly used for monitoring the daily activity of the person. The microphone is used for monitoring the user interaction and for collecting the user input if required.

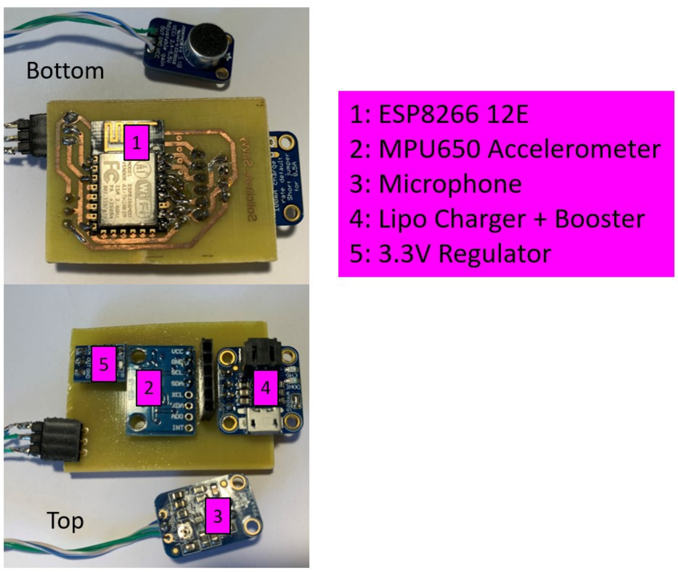


Fig. 2. SolicitudeSavvy neck wearable designed for real-time anxiety monitoring

C. *Werable EoG for detecting and reducing anxiety*

Electrooculography (EOG) is the measure of electrical potential between electrodes placed at points (above, below and either side) close to the eye. The electrodes record a difference in the standing cornea-retinal potential to determine which muscles are moving the eye and in which direction. Traditionally EOG utilizes Silver(Ag) electrodes to capture eye movement, and rely on amplifiers and signal conditioners to filter noise from data to determine eye movement. Electrodes rely on proper placement which can vary depending on face shape, electrode skin contact can be broken due to head orientation or movement, having metal diodes being a point of contact on skin causes irritation and pain making devices uncomfortable for prolonged periods of time. Traditional methods use an indirect method to extrapolate eye movement. In this research, the approach of directly capturing eye movement utilizing image processing and eye tracking avoids the use of silver electrodes, contact points and data filtering.
The features collected through the EOG includes eye event tracking such as the number of blink movements and longer eye gaze. Figure 3 shows the design implementation of the proposed wearbale EOG design. The data collected through the EOG framework is processed at the edge with the help of the single board computer.

VI. Implementation and Validation of SolicitudeSavvy framework

The proposed SolicitudeSavvy system is designed with the help of off-the shelf sensors, microcontrollers and single-board computer. The implementation and validation of the framework was done with both the EOG system and the neck wearable.

A. *EoG based eyewear for emotion recognition*

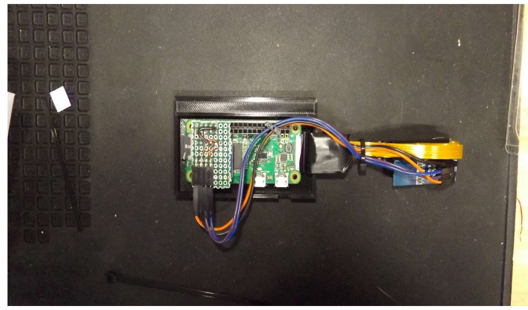
The device uses the Raspberry Pi Zero W, a Single Board Computer (SBC) to monitor both sensor and camera data. EOG is calculated and stored on board using the Open Computer Vision (OpenCV) library. Wireless transmission via Bluetooth and Wi-Fi can be sent in real time or in intervals based on completion of a dataset or wireless availability.

- The EOG camera: Captures snapshots or live video of the eye and calculates eye movement, light and dark adapted retinal response to stimulus.
  - Supports up to 1080p30fps video
  - Camera settings used for eye imaging: 640x480
- The Forward-facing camera: By default it is not enabled to conserve power and storage space until the user's focus is required. When enabled along with EOG the camera will pick up objects the user is focused on and for timing user reaction to stimulus. This supports up to 1080p30fps video.
- The Gyroscope: Can measure head orientation to further help in control-based applications. MPU6050 6 Degree of Freedom Gyroscope 131 degrees per second and the Embedded accelerometer has ±2-16g.
- The Display: Allows data, feedback and instructions to be displayed. The display used for this framework was SSD1306 32x128 OLED Display.
- Power source: The device can be powered by a standard usb battery bank.
- Software: Numerous python scripts were written to allow video capture or burst images at a rate of 15-20 fps while data for head movement and orientation is recorded. These still images are processed with the OpenCV library and then can be discarded to save storage space. The eye position and retinal size is recorded in a csv file and time stamped. Using a camera to capture Infared inamges allowed capture of low light images enabling more versatility in the use of the device.

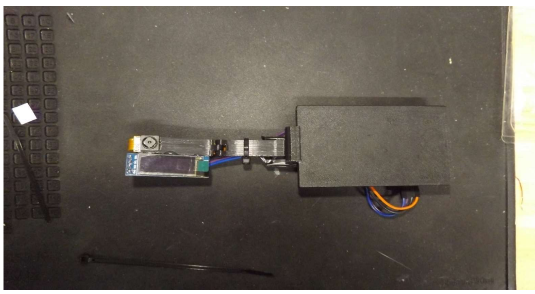
B. *Validation of the proposed neck wearable*

The neck wearable designed using the accelerometer and microphone embedded with the ESP8266 microcontroller was used to collect the daily activity data along with the user

(a)



(b)



(c)

(d)

Fig. 3. Design implementation of the proposed wearable EOG system a. Initial design for Head mounted unit; b. Front Head mounted setup; c. Rear head mounted setup; d. user view of the head mounted unit

interaction. Figure 4 shows the output waveform of the accelerometer used in the neck wearable. This accelerometer was calibrated with the FDA approved wearable Empatica E4, such that the accuracy of the proposed framework was highly reliable.

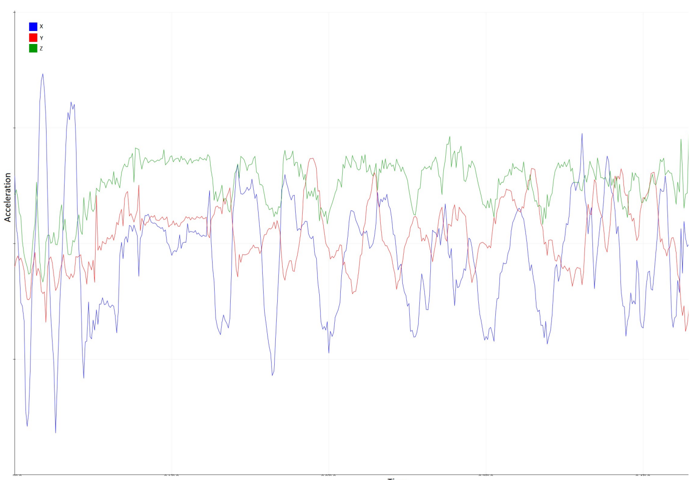


Fig. 4. Output waveform of the Accelerometer in SolicitudeSavvy neck wearable

C. Experimental Setup

An experimental setup with the EOG wearable and the neck wearable was done in real-time for collecting the mentioned features for anxiety monitoring. The data collected through the neck wearable was sent to the IoT cloud to further analyze the activity variability and the interaction variability. This output was displayed to the users through a custom-built user interface. The response time for the feature collection and display of the results was very minimal. The accelerometer calibrated using the FDA approved wearable, had an accuracy of about 97%.

By using the custom-built portable wearable EOG system, eye movement data can be logged for prolonged periods of time while having little impact on a person's mobility. Due to minimal mobility restrain the user may encounter environmental stress which would cause movement and sweating which may impede use of electrodes. The data from the gyroscope, cameras and calculations can be stored onboard the device, or recovered wirelessly or through a usb drive. This process can be automated for a clinical testing environment or customized as needed for general use. For use in remote guidance and information systems the display can give simple directions, images of wearers focus can be sent wirelessly in real time to a more powerful system for analysis.

VII. Conclusions and Future Research

The proposed research aims in developing a real-time anxiety monitoring framework with help of custom-built wearable EOG system and a neck wearable. A proof-of-concept of the proposed research was designed with the help of off-the-shelf components and the validation of the same was done with the help of FDA approved wearable. The data collected through the EOG wearable was stable and the data acquisition was achieved for prolonged periods. This proposed framework can be a significant contribution to the research in real-time anxiety monitoring as currently most of the work is done in closed laboratory setting. Future research involves developing algorithms for clearly differentiating the state and trait anxiety and the anxiety induced due to the social environment. Additionally, the outcomes of the experiment will be made available as public datasets in platforms such as Physionet.

VIII. Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No.OAC-1924117 and the University of Texas at Tyler New Faculty Research Grant 2019-2020. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the Office of Sponsored Research at UT Tyler.

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