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# Comprehensive Data Collection Framework for Mental Stress Monitoring

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## Abstract

To maintain good health, accurate recognition of the body's responses to stress and timely management of stress is important. However, recognizing such reactions is difficult since people react to stressful events in various ways. Accordingly, we propose a stress monitoring framework to comprehensively examine people's physiological and behavioral reactions to stressors. Our framework consists of (i) comprehensive data collection, (ii) stress inducing experiment in a laboratory, and (iii) signal examination in real-time and after data collection. Through preliminary experiments, we have demonstrated the feasibility of our framework in examining people under stressful events. Finally, based on the proposed framework, we will establish a database contributing to the mental health sensing research.

## Author Keywords

Stress recognition; Wearable devices; Physiological signal monitoring; Activity monitoring

## ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous; J.3 [Computer Applications]: Life and medical Science - Consumer Health

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## Introduction

In modern society, people are exposed to various stressful events. If they are constantly exposed to stressful incidents, this can cause various health problems, such as depression, cardiovascular disease, etc [14]. Recognizing when people are getting stressed and properly relieving them has been an effective method to maintain good health.

In efforts to monitor people's mental health, various approaches have examined people's physiological and behavioral responses to stressful events [4, 6, 12, 5, 8, 3, 10]. However, since these studies utilize the limited number of sensors, the proposed systems are insufficient to fully understand how people react to stressors. Under stressful events, people have not only various responses but also individual varieties. For example, when people are presenting in front of a large crowd, some might sweat while others might shake their hands. Further, some might breathe irregularly whereas others might breathe increasingly fast under stressful episodes. Accordingly, people experiencing stressful events should be examined in holistic aspects using various sensors considering diverse kinds of responses to stressors.

Accordingly, we propose a comprehensive framework for monitoring people during stressful events. Our framework collects people's physiological sensor data and their movements and further organizes the collected data as a database. In the framework, three commercial wearable devices, Empatica E4, Zephyr Bioharness Module, and LG Watch Style, and a IP (Internet Protocol) camera collect 8 different types of sensor data at the same time. As for the data collection, we have utilized popular stressors in existing research to induce stress to participants [1, 11, 7]. In addition, we also have developed a program, which monitors sensor data collected during the experiments. The program receives

various signals from the wearable devices, checks the robustness of real time connection between wearable devices and the server, and visualizes the collected data comprehensibly. Based on the proposed framework, we plan on building a robust database which broadens the understanding of mental stress and further contributes to the affective computing and mental health sensing communities.

## Related works on stress recognition

Conventional researches have utilized various sensors to estimate mental stress in several contexts. The physiological sensors typically exploited in those researches are EDA (electro-dermal activity), PPG (photoplethysmogram), ECG (electrocardiogram), and Resp (respiration); which measure skin conductance, heart rate, heart activity, and breathing rate, respectively. In addition, accelerometer, gyroscope, image, and audio sensors are exploited to examine people's behavioral features, such as movements, facial expressions, voice and so on.

To continuously and unobtrusively monitor such signals, conventional researches have utilized various wearable devices. Table 1 compares the state-of-the-art studies on stress estimation against the proposed framework in terms of the used sensors. Those researches have appropriately captured whether people were stressed or not, but can be insufficient to cover various responses against stress. For example, [3, 8, 9] are not able to monitor people's behavioral responses during experiment, such as shaking one's hands, since accelerometer and gyroscope are excluded in the framework. Further, [4] fails to monitor people who show little facial expression and have no habitual movements under stressful episodes. In [6], movement data are just used to remove noisy information and they fail to capture behavioral features caused by stressors. [10] does not investigate changes in heart activity under by stressful inci-



**Figure 1:** The wearable devices used in the proposed framework should minimize discomfort and restriction on a person's movement

**Table 1:** Under the proposed framework, people's physiological and behavioral reaction can be comprehensively examined

Reference	EDA	PPG	ECG	Acc (wrist)	Acc (chest)	Resp	Image	Audio
Proposed method	✓	✓	✓	✓	✓	✓	✓	✓
Mozos, 2017 [10]	✓	✓			✓			
Chan, 2016 [3]			✓					✓
Koo, 2016 [8]	✓							
Gjoreski, 2016 [5]	✓	✓		✓				
Wu, 2015 [12]			✓		✓			
Hovsepian, 2015 [6]			✓		✓	✓		
Gao, 2014 [4]							✓	

dents and further, [12] lacks in considering the skin conductivity of people.

To properly capture various responses of people when getting stressed, we construct a comprehensive data collection framework using 8 sensors as described in Table 1. Because the framework examines people's reaction in multiple perspectives, we should be able to not only understand various kinds of people's reaction to stress, but also create a stress estimation model which considers individual characteristics.

## Comprehensive Data Collection Framework

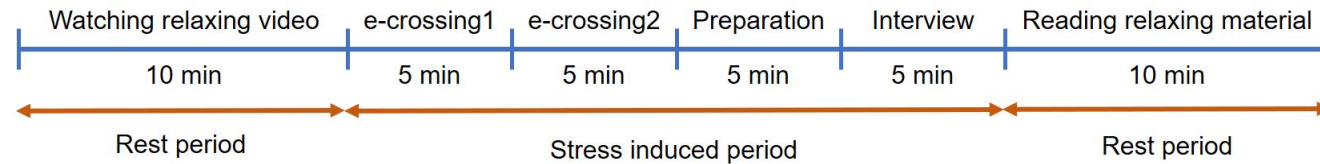
### Data collection method

In the proposed framework, the Empatica E4 Wristband, the LG Watch Style, the Zephyr Bioharness Module, and the IP (Internet Protocol) camera examine people's reactions to stressors during the experiment. These devices can be easily and comfort worn by people while supporting the sensors widely utilized in stress estimation research. Table 2 describes each device's embedded sensors and body parts to be worn on. Figure 1 shows one participant wearing all devices. For accurate data collection and comfort of wearing, we have empirically chosen the location of the devices on the body.

The Empatica E4 Wristband is worn on non-dominant hand to monitor skin conductance, heart rate, and movement of the hand. One of the advantages of Empatica E4 is that EDA signals are measured from the wrist rather than fingers. Various EDA sensors typically measure skin conductance from fingers which limits one's activity while wearing the sensors. To minimize the discomfort in wearing the device, we utilize Empatica E4 Wristband of watch-type band on wrist. Further, LG Watch Style is a state-of-the-art smartwatch embedded with accelerometer and gyroscope. We utilize the devices to monitor hand movements of people. Since smartwatches are widely used in everyday life, the participants should not be awkward in wearing the device while being able to capture hand movement. Zephyr Bioharness Module is a chest-worn device close to the heart. The device is widely used for monitoring heart activity of athletes during training and in games. Using this device, people's physiological signals can be accurately measured even in the presence of violent movements. Additionally, we utilize an IP camera to monitor participants at a distance. This captures not only several physical movements and facial expressions but also voice. We aim to acquire meaningful data for estimating stress.

**Table 2:** Each device in the proposed framework supports beneficial sensors to estimate stress on comfortable locations

Device	Sensor	Features	Location
Empatica E4	EDA PPG Accelerometer Temperature sensor	Skin conductance Heart rate Movement Body Temperature	Non-dominant hand
LG Watch Style	3-axis Accelerometer 3-axis Gyroscope	Directional movement of hand Rotation angle of hand	Dominant hand
Zephyr Bioharness	Respiration sensor ECG Temperature sensor 3-axis Accelerometer	Respiration rate Heart rate variability Body Temperature Posture	Around chest
IP Camera	Image sensor Audio sensor	Video of experiment Voice and noise	Facing participant



**Figure 2:** During the experiment, each test participant will go through 20 minutes of relaxation period and 20 minutes of stress induced period.

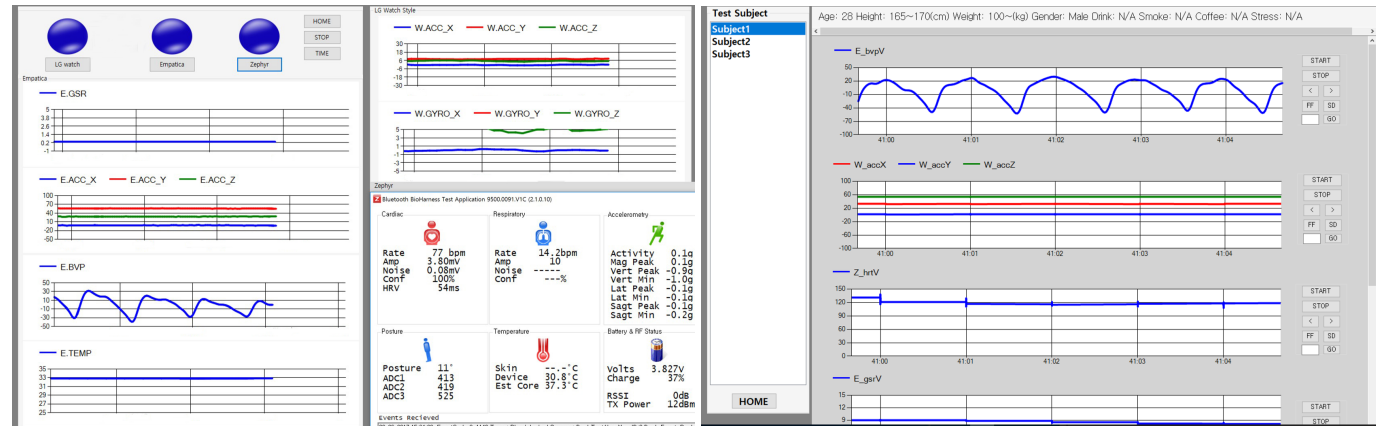
#### *Experimental scenario*

To understand how people react against stressful episodes, we have designed a laboratory experiment. Our experimental scenario consists of setup, rest, stress induction, recovery, and debriefing. In the setup stage, participants will be given instructions on the tasks that they will be performing and how to wear the devices. To remove any potential bias that can be caused from prior knowledge, we disclose the real purpose of the experiment at the debriefing stage. During the debriefing stage, they will be told the goal of the experiment and detach the devices. As for inducing stress to people, the experiment participants of the conventional works have performed utilized cognitive and socio-evaluative works. Since it has been demonstrated that they are successful in inducing stress [1, 11], we base the design of our experiment on such tasks. Figure 2 shows the experimental timeline for one participant excluding the setup and the debriefing phases.

After the setup phase, the data collection from three devices will start and the participants will move on to the rest period to neutralize their emotions before inducing stress. In the rest period, the participants will be watching a relaxing video for 10 minutes, where we have empirically decided the length of the period. The video is a clip showing natural environment, such as flying birds or a lake, with slow-tempered relaxing music.

For the first stressor of our experiment, we utilize "e-crossing" [7] where the participants exercise a cognitive task. In this period, the participants are given a piece of paper filled with texts and are instructed to cross out as many "e"s as possible. This task lasts for 5 minutes and we call this sub-period as "e-crossing1". After "e-crossing1" is finished, the participants are given another piece of paper with different texts and they would conduct a similar task. In this section, they are instructed not to cross out "e" if there are three or more "e"s in one word. For example, the participants should not cross out "e"s in the word "between" since three "e"s are in this word. This period is called "e-crossing2" and lasts for 5 minutes. According to [7], people enter the stage of ego-depletion during the tasks and eventually receive stress by performing such cognitive task.

After finishing the "e-crossing", the participant is involved in a socio-evaluative task, an interview. An interview has been widely utilized for inducing stress [1, 11]. Moreover, the participants are forced to speak in a non-native language to induce even more stress. For the first part of this stage, which we refer as "Preparation" stage, the participants are given a piece of paper with the interview questions and prepare the answers for 5 minutes. After 5 minutes, a native speaker will come into a room and will conduct the interview for 5 minutes. The interviewer will ask previously handed out questions and some follow up questions until the given



(a) The incoming data from all three wearable devices can be monitored in real-time

(b) The form visualizes the database and each graph can be manipulated in various ways

**Figure 3:** The program is a centralized data collection software where the devices' connectivity, incoming data and the constructed database can be viewed

time is over.

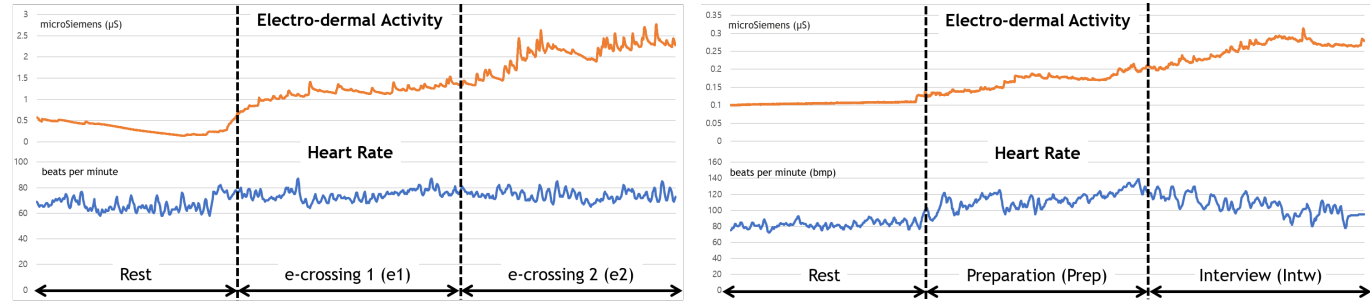
Once the whole stress induction periods of "e-crossing" and the interview are finished, the participants are given a material to read for 10 minutes to recover from the stress. During this period, which we refer as "Recovery", the participants will be given a magazine which contains emotion neutral contents. Once this period is over, we stop collecting the sensor data as well.

#### Data examination tool

To easily check the connection status between wearable devices and a server, and to intuitively examine incoming signals, we have developed a C# application. The application running on the server (i) opens a connection with each device and receives data from each device, (ii) monitors the

received data in real time, and (iii) organizes the data into a database and visualizes them. Figure 3 presents main pages of our application to be utilized in the experiments.

Figure 3a shows the form in which the three wearable devices can be connected to the server and connectivity of the devices during the experiment can be monitored. Empatica E4 and Bioharness module communicate with the server using Bluetooth communication. As for the LG Watch style, the device communicates data over TCP (Transmission Control Protocol) communication. Once each device is successful in connecting to the server, the color of the corresponding device's circle will change to blue. As soon as the data are received by the server, the program starts to plot the data on the graph and saves the data to csv file simultaneously. As for the Bioharness module, since the



(a) "e-crossing" experiment increases participant's overall EDA and heart rate

(b) During the interview experiment, the overall tension that the participant receives increases

**Figure 4:** The participant's physiological signals change while performing the proposed stress inducing tasks

manufacturer does not provide sufficient API for developers, we utilize the sample bluetooth communication software provided by the company. The program monitors if the device is correctly acquiring signal and the sensor data are saved within the device. The collected data is later exported to the server.

Each sensor data is saved at a separate csv file. Later, the collected data are organized into the database and are later visualized in Figure 3b. On the box located at the left of the form, there shows the list of the participants where each participant is identified as an unique subject number. When each subject number is clicked, the collected data are shown in the form. The personal information is shown on the box located at the top of the form. Note that these data represents statistical information only for the research purposes and cannot be utilized to break one's privacy. Each sensor data is visualized in a graph. Once the start button is pressed, the graph shows how the sensor data changes according to time. The speed in which the program displays the data can be manipulated. Further,

the program can be fast-forwarded or reversed to any given time chosen by the program user.

### Preliminary Experiment Result

To examine the feasibility of the proposed framework and effectiveness of the proposed stressors, we have conducted preliminary experiments. Four people participated in the experiment. The participants went through the rest period and either "e-crossing" or interview while wearing all three devices.

Figure 4 displays the graphs of EDA values measured from Empatica E4 and the heart rate calculated from Zephyr Bioharness module. Figure 4a is the graph of the participant's change in physiological signals during "e-crossing" and the participant in Figure 4b went through interview. Through the preliminary experiments, we were able to examine the changes in physiological data during stress induction periods. In both scenarios, both of the participants' EDA value and heart rate value during stressor activities were higher than those of during Rest period.

(bpm)	AVG	MAX	MIN
<b>Rest</b>	67	82	58
<b>e1</b>	74	87	64
<b>e2</b>	73	85	65
<b>Rest</b>	81	93	64
<b>Prep</b>	110	134	76
<b>Intw</b>	107	139	78

**Table 3:** The participant's heart rate were higher during the stress inducing tasks compared to that of during rest period.

In addition to the increases in the values of EDA and heart rate, we were able to observe how people have various reactions to different types of stressors. Compared to the participant performed the interview, the participant who performed "e-crossing" showed more abrupt increased in the EDA values. Such peaks are called as Skin Conductance Responses (SCRs) and such phasic EDA reactions often occur when people are exercising cognitive tasks, such as decision making or anticipation [2]. Even though both tasks increased the overall level of EDA values, more SCRs can be examined during "e-crossing" than during the interview since people more frequently involve in decision making during "e-crossing" than during an interview.

We have also examined how people's heart rates are influenced during each task. The average heart rate of both participants were higher during stress inducing period than that of rest period. Table 3 shows the average, the minimum and the maximum heart rate of each period for each experiment. During the stress induction period, the overall heart rate was higher than that of during rest period. However, the heart rate of participant in Figure 4a were relatively steady compared to that of the participant in Figure 4b. We hypothesize that the participant in Figure 4b were able to control this heart rate by controlling how he breathes while he was talking.

## Conclusion

In this work, we have proposed the comprehensive framework for monitoring people under stress. Physiological, motion and multimedia sensors from three commercial wearable devices are used to monitor people's various reactions to stressors. We have also designed a stress inducing experiment where participants will exercise cognitive and socio-evaluative tasks. To assist with the experiment for the signal checking and data collection, we have developed a

C# program which monitors incoming sensor data in real-time and later visualizes the constructed database. Through the preliminary experiments, we were able to examine the effectiveness of the proposed stressors in inducing stress to the participants. During the stress induction period, the participants' physiological signals not only increased but also showed different reaction to different kinds of stressors.

The proposed framework and the experimental setup have been approved by Yonsei University Institutional Review Board. As for the future work, based on the data collected from the experiments, we plan on building a stress estimation model. In particular, we expect to build not only a personalized model but also an universal model where a model can be applied to various types of people. As for improving our framework, we further plan on investigating the effective body parts to attach each sensor. For example, EDA can also be measured from a person's ankle [13]. We plan on investigating the sensing locations in terms of accuracy, effectiveness in estimating stress and comfortability in wearing the sensor in various contexts. Finally, the physiological and movement database will be open-sourced to contribute to the mental health sensing community.

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