Aequorin: Design of a System for Reduction of the User's Stress in One Day

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This paper describes the design of *aequorin* which is the system for measurement and reduction of the user's stress for a day. This system consists of a wearable device which is composed of a pulse sensor, MCU (Micro Control Unit) board and iPodTouch and also a rocking chair with biofeedback function embedded with LED lights and a display for stress reduction experience. After the user comes back home, the user experiences the stress reduction with the log data measured for the day through the wearable device. The system adopts two approaches for stress reduction; one is an indirect presentation of the stress information as biofeedback in which the system illuminates the LED lights with 1/f noise according to the amount of stress, and the other is a direct presentation of the stress information composed of stress values and their time codes as biofeedback to the display. After introducing the design and implementation of stress reduction, this paper describes about a hearing to validate these approaches, and introduces the limitations of this system.

Biofeedback, Monitoring, Stress, 1/f

I. INTRODUCTION

There are some researches about health care systems called *Pervasive Health Care* using ubiquitous computing technologies [1]. Behind this background are improvements of constant connection environment by wireless communication and mobile devices, downsizing and unwiring of sensors and downsizing and power saving of batteries. The purpose of pervasive health care system is to monitor the user's breath, pulse, blood pressure and so on and then to make appropriate procedures if an emergency arises. For example, Elite Care [2] is a health care system adopted by some care facilities for the elderly. It offers high quality services including emergency care by making use of sensor network and database for monitoring the residents. Ubiquitous ECG (Electrocardiogram) Monitoring System [3] utilizes Zigbee for short distance wireless communication for a purpose of energy saving and low cost. This system adopts SIP protocol for emergency calls which is used by IP phones. Apart from these systems, aequorin focuses on stress reduction as one of the preventive cares to mental diseases.

Aequorin is a system with a purpose of measurement and reduction of the user's stress for the day. The system consists of a wearable device which is composed of a pulse sensor, a MCU board and an iPodTouch and also a rocking chair (Figure 1) embedded LED lights and a display for stress reduction experience. First of all, the user can record his/her stress data by wearing the pulse sensor on the ear lobe connected to the iPodTouch. Next, the user can upload the recorded stress data with an iPodTouch application to the server. After going back home, the user sits on the biofeedback chair and downloads the recorded data to the local machine with another iPodTouch application. When the user starts the stress reduction experience, the system presents the stress value and their time codes for the day on the display beside the chair. At the same time, the system illuminates the LED lights with 1/f noise to the veil surrounding the chair while playing the recorded stress data. The LED colors are decided by the user in advance with the iPodTouch Application.

Aequorin aims not only to measure the user's stress for the day but also to reduce it. Most of the people in the cities feel stress more or less in a variety of situations such as offices, schools or at home, and it is affirmable that stress is one of the causes for serious diseases. With these reasons, it is desirable for every person to do appropriate stress management. To enable stress reduction, aequorin adopts two approaches. The first approach is an indirect presentation of stress information according to the amount of stress information by an arbitrary LED color. At the same time, aequorin introduces 1/f noise to illuminative processing with the arbitrary color. The usage of stress information is indirect, but this is a direct approach in terms that illuminative processing would reduce user's stress. The second approach is a direct presentation of stress information composed of stress values and their time code. Although the usage of stress information is direct, this is an indirect approach in terms that the direct presentation would have the user recognize stress and prompt to govern stress by oneself. The purpose of this paper is to validate how or for whom these two approaches are effective.

Fig.1. The biofeedback chair

II. RELATED WORKS

Stress is defined as the nonspecific response in an organism when a variety of external stimuli make emotional or physical threat. This definition was by an endocrinologist Hans Selye [4]. Selye called it the *stressor* which perceived threat and divided them into four categories; physical stressor (fridgeness, noise, radiation etc.), chemical stressor (enzyme, medicine etc.), biological stressor (inflammation, infection etc.) psychological stressor (anger, anxiety etc.). In addition, Selye found that all animals presented a very similar reaction when they were exposed to the continuous stress and formulized it as General Adaption Syndrome (GAP). GAP has three stages – Alarm, Resistance, Exhaustion - and the long Exhaustion

stage can result to death. In this research, we focus on the psychological stressor.

Frustration, recognized as a very similar concept as stress, means the condition where one is obstructed from accomplishing a personal goal, and one of the psychological stressor. Some researchers in Affective Computing, with a purpose of development to recognize, analyze and process human's emotion, has measured frustration as a part of a measurement of emotion. For instance, Nakatsu developed an emotion analysis system using the human's voice by neural network and a large scale of speech database and measured 8 emotions including frustration [5]. Lisetti developed an emotion analysis system using pattern machining with face images on neural network and another emotion analysis system based on GSR (Galvanic Skin Response), pulse, body temperature, and measured frustration [6]. Compared with these systems, Puri developed a system which can detect the user's emotion through the face image of the user captured by a thermograph camera based on the theory that an amount of frontal vessel enables to judge stress [7]. In this research, we utilize one of the unconscious biological data because some noises or intentional concealment by the user may arise in the case of image processing or audio processing.

There are a wide variety of methods for stress measurement from commercial to research. For example for the commercial, emWave [8] is a device with a pulse sensor. The user can measure stress wearing the sensor on the ear lobe or on the finger. This device has a full color LED and is supposed to be used for improvement of pulse rate according to its lighting up; red, blue or green. Next, Stress Thermometer [9] is a system consisting of a probe in order to get stress value from the body temperature on the hand and a device to display its temperature. On the other hand, for instance for research, Cocoro Meter [10] is a device to judge whether it is comfortable or not by using salivary amylase which changes according to the sympathetic nervous activities. Next, eWatch [11] is a wearable device for the wrist with Bluetooth which can sense lights, motions, sounds and body temperature and actuate sounds, images and tactile notifications, and measure stress by body temperature changes. Finally, Pmobile [12] is a stress monitoring system using a wireless pulse sensor and an iPAQ. When it detects stress, the user can add an annotation such as talking, meeting, relaxing, working, fun, eating, exercise, commute, personnal. In this research, we adopt a method to measure stress that does not make the user feel any load in wearing a sensor and that does not disturb the user's action. It is because we think it preferable not to add any physical or psychological stress in the method itself in the case of daily use.

Some researchers use 1/f noise to reduce stress. 1/f noise is a signal which has the spectrum that the spectra density varies inversely to frequency f and is discovered in different phenomenon in nature [13]. For example, 1/f noise is included in pulse beat, waving of candle flames, swinging of trains, sound of a stream and so on. Musha [14] found that transcutaneous pain reduction is more effective when the patients listened to a music piece applied with 1/f sequence. Tokuhisa designed an interactive art piece Suirin [15] which the user can manipulate water in the container as an interface to generate insect's whispering including 1/f noise and to control LED lights. The purpose of it was the healing of auditory, tactile, optical and olfactory sensation and it found that healing with tactile sensation is the most effective as a result of user experiments. In addition, Suirin adopted not only 1/f noise but also illuminating effects based on traditional color therapy [16] [17]. From these prior works, in this research, we adopt illuminative processing with 1/f noise and color effects on the illumination as one of the methods to reduce stress.

Some researchers utilize biofeedback as stress reduction. Biofeedback is a process that enables an individual to learn how physiological activities change to improve health and performance. To be precise, it aims to promote changes in thinking, emotions and behaviors by measuring physiological activities such as brainwaves, heart functions, breathings, muscle activities, and skin temperature and presenting him/her this information [18]. For example, Stress Eraser [19] is a biofeedback device to improve the way of breathing. When the device detects stress by HRV (Heart Rate Variability) graph displayed on the device, the device indicates to improve patterns of breathing to the user in order to ease stress. Affective Health [20] is an ambient biofeedback application to visualize the measurement of stress information on a cellar phone with a pulse sensor. The developer thinks it more stressful to give the information directly to the user, and represents its ambience. From these prior works, in this research, we adopt the direct and indirect presentation of stress information based on biofeedback as methods to reduce stress.

III. RESEARCH PROBLEM AND APPROACH

The problem of this research is the development of a pervasive healthcare system to adopt the method not only to measure the user's stress but also to reduce the user's stress for the day. Based on this research problem, this paper validates two approaches as follows to reduce the user's stress.

1. Direct presentation of the stress information composed of stress values and their time code as biofeedback on the display.
2. Indirect presentation of the stress information as biofeedback in which the system illuminates the LED lights with 1/f noise according to the amount of stress values.

Approach 1 is based on a hypothesis that stress will be reduced through biofeedback as a re-experience of the stress for the day with the direct presentation of the stress information. To be precise, we suppose that the cognition of conscious and unconscious stress directly felt by the user would prompt to recover oneself of stress and finally the user would be able to reduce stress. Approach 2 is based on a hypothesis that stress will be reduced through illuminating processing with 1/f noise as an indirect presentation of the stress information. To make the user select his/her favorite color in approach 2 is to minimize the influence of a color effect in the experiment, and aims to dissolve the gap between general color effect theory and its influence to the user. For example, some users would feel discomfort to green, though it is said to give most people psychological relief in the color effect theory. Next, we will introduce the detail of aequorin which is the system for implementation of these approaches.

IV. SYSTEM

The system of aequorin consists of a wearable device composed of a pulse sensor, a MCU board and an iPodTouch,

a server, a local client to process illuminating effect and to present the stress information using the log data and a biofeedback rocking chair with LED lights and an embedded display (Figure 2). In this section, we will see the details of the system from hardware and software.

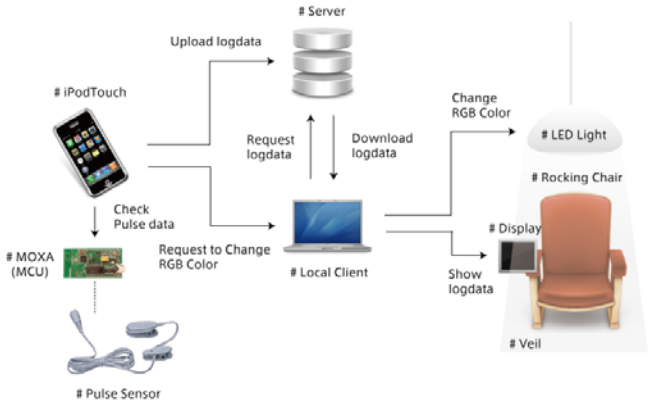

Fig.2. Aequorin System

A. *Hardware*

The wearable device consists of a pulse sensor, a MCU board and an iPodTouch. A rocking chair, as the equipment in order to experience the stress reduction based on biofeedback at home, is composed of a display to present the log data and a LED unit embedded LED lights to illuminate an arbitrary color to the veil around the chair. In this sub section, we will introduce the detail of the wearable device and the biofeedback chair.

Wearable Device

The pulse sensor is the type wearing on the ear lobe (Figure 3). This is because of two reasons; one is that there is no obstacle to move their hands, arms or other parts of the body when the user wears a senor to measure his/her pulse; the other is that the system measures it real-time. We selected BYC-01 by Omron, developed an original amplifying circuit, and adjusted it for the volt to change between 0V to 5V.

We use moxa [21] [22] as a MCU board in order to analyze the signal of the pulse sensor, to acquire the stress value and to send it to iPodTouch (Figure 3). Moxa is a MCU board using ATMEGA 128 included xtel which is a ubiquitous content platform having been developed by Keio University Ubiquitous Content Project. Moxa utilizes the lower layer of Zigbee, and is capable of wireless communication for short distances as well as the assignment of communication channel. A PodBreakout (DEV-08295) is used for the connection between moxa and iPodTouch.

Biofeedback Chair

The LED unit (Figure 4) above the biofeedback chair is composed of some strip type LED lights and a DMX controller. The LED lights are Link LED X by Dialight. The DMX controller in order to change digital data from the local client to DMX signals is lanbox-lcx by CDS electronics. With these hardware, the user can control each RGB parameter on real-time via an original application for iPodTouch and can directly change the illuminating color.

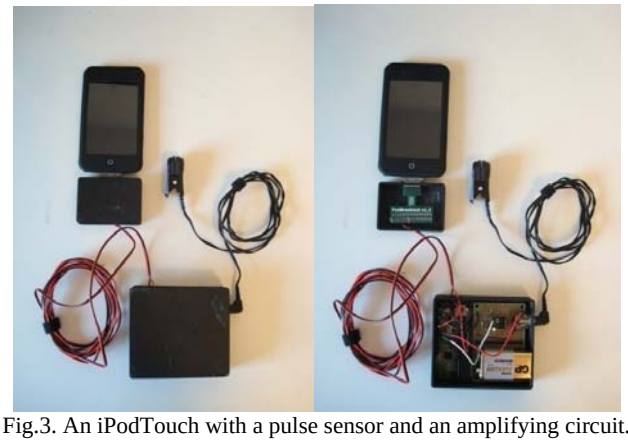

Fig.3. An iPodTouch with a pulse sensor and an amplifying circuit.

Fig.4. LED lights hanging from the ceiling over the chair can illuminate an arbitrary color to the veil surrounding the chair

B. *Software*

The software on aequorin consists of an iPodTouch applicaition “ECGUploader” to record stress value based on the data from the pulse sensor and to upload the log data, another iPodTouch applicaition “LEDController” to download the log data to the local client, to control the color of the LED lights and to start the stress reduction experience, and a Mac OS X application “ChairController” to illuminate LED lights and to present the stress values and their time codes to the embedded display according to the requests from the LEDController. In this section, we will describe the detail on each application.

ECG Uploader

ECGUploader uses NSTask class on Cocoa Touch / Foundation framework and launches some python scripts. The python scripts do the tasks as follows when they get each event through the user interface implemented on UIKit framework.

1. Request to start measuring the user’s pulse (button: Start)
   i. Get the time code when recognizing stress.
   ii. Make a log data file with different file names on every day.
   iii. Store each stress value and each time code to the log

data file.

2. Stop measuring the user's pulse (button: Stop)
3. Upload the file to the server (button: Upload)

The pulse data is acquired by measuring the pulse potential obtained by the pulse sensor worn on the ear lobe. ECGUploader uses a JavaScipt file on the moxa so as to acquire the pulse data itself. The script measures the number of cycles of the potential change for 60 seconds and returns the pulse data to ECGUploader. ECGUploader stores a pulse data for the first 60 seconds as the default value, recognizes its condition as stress when the difference between the default value and the obtained data gets above 20, and records the data to the log data file.

In the LEDController, we implemented OSC (Open Sound Control) on Cocoa Touch / Foundation framework and CFNetwork framework to communicate with the OS X application ChairController. LEDController sends the corresponding IDs and data to ChairController when it gets each event through the user interface implemented on UIKit framework.

LEDController requests these 3 tasks as follows.

1. Request to download the log data to the local client (button: Download)
2. Request to control each RGB parameter on the LED lights (button: each colorChange R/G/B)
3. Request to start the stress reduction experience (button: Start)

Download button, each RGB slider and Start button each have specific IDs. Download button and Start button sends Boolean value with the IDs and each RGB slider sends an integer number from 0 to 255 with the IDs.

aequorin

ChairController does the three tasks as follows according to each request from LEDController.

1. Download the log data when receiving the download request.
2. Control each RGB parameter of the LED lights on real-time when receiving each RGB control request.
3. Start the stress reduction experience when receiving the start request.

The stress reduction of the third task is divided into 2 approaches; one is the direct presentation of the stress information composed of stress values and their time code as biofeedback on the display, and the other is the indirect presentation of the stress information as biofeedback in which the system illuminates the LED lights with 1/f noise according to the amount of the stress values.

The direct presentation of the stress information is to display the stress values and their time codes in order which are the times when the user felt stress for the day on to the monitor embedded near the arm rest of the rocking chair. Each stress value and its time code is displayed 1 second per 1 row on the log data (Figure 5). If the time codes are played for 1 minute, it means that the user felt stress for about 1 hour per day because one pulse data is measured for 1 minute duration. The direct presentation on the display is based on the hypothesis that the re-experience of stress which the user felt consciously or unconsciously has some reset effect towards the following day.

Fig.5. Direct presentation of the stress value and its time code on the embedded display.

The indirect presentation of the stress information is to process the illumination of the LED lights with 1/f noise to the arbitrary color selected in advance via LEDController by the user according to the amount of the stress value. The user can control each RGB value with 255 grades and can apply 1/f fluctuation to the illumination by adding 1/f noise to the RGB value. The experience duration depends on the amount of the log data. To be precise, the system illuminates 1second per 1 row on the log data, which is the same as the direct presentation on the display. After the system reads the last row on the log data, it will stop the fluctuation on the illuminating process and then change the LED lights from the selected color to white (R: 255 B: 255 G: 255) as the cue that the experience is over. The illuminating process with 1/f noise is based on the hypothesis that the re-experience of stress which the user felt consciously or unconsciously has some reset effect towards the following day.

V. EVALUATION

A hearing was done to validate two approaches of the stress re-experience as follows with a purpose of stress reduction.

1. Validation of the direct presentation of the stress information on the display
2. Validation of the indirect presentation of the stress information with the LED lights by the illuminating process with 1/f noise

14 women and men joined the hearing and these subjects consisted of researchers, students in graduate schools, and businesspeople working at private companies. Before the hearing, we introduced the description of aequorin to the subjects. Then, we had them experience aequorin with a sample data which has the stress information for 90 seconds and was prepared for this hearing in advance. After the experience, the subjects answered some questionnaires and replied to free opinion verbally. The questionnaires and their options are in Table 1.

TABLE1. The questionnaires and their options for user's hearing

questionnaires	options
1. Did you feel 1/f noise in the illuminating process?	a. Yes b. No
2. Do you think that it is effective to experience the illuminating process with 1/f for stress reduction?	a. Strongly agree b. Agreeable c. Not agreeable d. Strongly disagree
3. Do you think it effective for reducing stress to re-experience the time when you felt stress?	a. Strongly agree b. Agreeable c. Not agreeable d. Strongly disagree

First, we checked the result of the total subjects. For the first question, 13 of 14 subjects (93%) felt 1/f noise in the illuminating process. Next, as we summarize the second question asking the validation of the illuminating process with 1/f noise, the most dominant option was "b.Agreeable" (36%). However, in case of the majority, negative answers were dominant (c+d: 58%). Finally, as we summarize the third question asking the validation of the direct presentation on the display, the most dominant option was equivalent between "b.Agreeable" (36%) and "C.Not agreeable" (36%). But, in case of the majority, negative answers were dominant (c+d: 57%).

Next, we divided 14 subjects into two groups; one is a group of researchers and students in graduate schools as the researcher group; the other is a group of people working at private companies as the businessperson group. Then we filtered all the results by these groups. Firstly the result of the researcher group is in Figure 6. For the first question, 7 of 7 subjects (100%) felt 1/f noise in the illuminating process. Next, as we summarize the second question asking the validation of the illuminating process with 1/f noise, the most dominant option was "b.Agreeable" (57%). In case of the majority, positive answers are also dominant (a+b: 57%). Then, as we summarize the third question asking the validation of the direct presentation on the display, the most dominant option was "b.Agreeable" (57%). And, in case of the majority, positive answers were dominant (a+b: 71%). In addition, some researchers in the free opinions answered about annotation such as "it is better to add the geographical information" and "The function to record some physical information when feeling stress is preferable."

Secondly, the result of the businessperson group is in Figure 7. About the first question, 6 of 7 subjects (100%) felt 1/f noise in the illuminating process. Next, as we summarize the second question asking the validation of the illuminating process with 1/f noise, the most dominant option was "c.Not agreeable" (43%). In case of the majority, negative answers were also dominant (c+d: 72%). Then, as we summarize the third question asking the validation of the direct presentation on the display, the most dominant option was "d.Strongly disagree" (57%). And, in case of the majority, negative answers were dominant (c+d: 71%). In addition, some businesspersons in the free opinions answered such as "Re-experience of comfortable information rather than stress is preferred", "Recalling negative memories are not preferred" and "The re-experience itself is totally stressful as an individual".

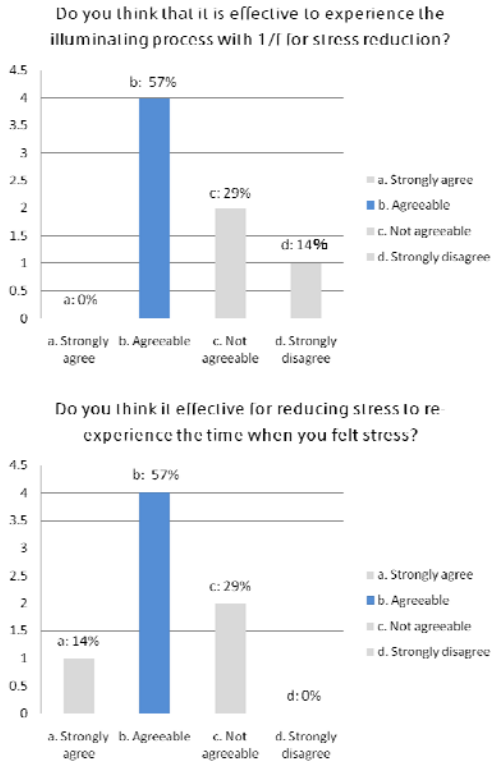

Fig.6. the results of the researcher group
upper. The result of question 2; lower. The result of question 3.

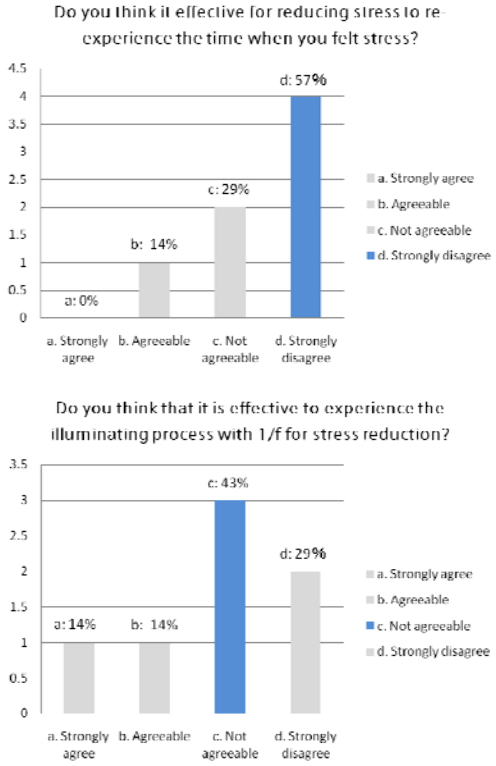

Fig. 7. the results of the businessperson group
upper. The result of question 2; lower. The result of question 3.

We found from these results as above that two direct and indirect approaches adopted in aequorin in order to reduce user's stress come to the opposite results between the

researcher group and the businessperson group. To be precise, the researcher group felt 1/f noise and answered not only that the majority of them felt stress reduction was effective in the illuminating process with 1/f noise, but also that most of them thought the re-experience of stress effective. On the other hand, the businessperson group felt 1/f noise, but considered the illuminating process and the re-experience of stress as negative. We suppose that these differences are contributed to the possibilities that researcher group have the responsibility to manage themselves and gets feedback and modifies them. However, employers have the responsibility to manage their employees and employees generally have fewer points which they can modify by themselves. We suppose that the businessperson group does not recall the stress for the day directly or indirectly because they cannot handle it and cannot but help forgetting them.

VI. DISCUSSION

We describe two limitations of this system; the measurement method of user's pulse and the evaluation. This system utilized two approaches; the direct and indirect representation of stress information in order to reduce user's stress. In terms of sorting the results of the hearing by occupation, the researcher group had positive opinions about the illuminative effects with 1/f noise and the re-experience of stress. On the other hand, the businessperson group had positive opinions about the former and negative opinion about the latter. Through the hearing, the limitations of these approaches emerged.

Firstly, the measuring method of stress has limitations, especially with the pulse sensor. One is the problem that pulse increases through physical activities in daily life. The present system cannot distinguish the condition of psychological stress from the daily activities. Another problem is that the pulse sensor is the type which needs to be clipped to an earlobe. It is possible that the cable for the sensor is annoying for the user and wearing the sensor itself gives the user stress. We hope to develop an annotation function when feeling stress as the countermeasure of the limitation. For example, it is preferable to insert some information about place, emotion or other conditions to his/her log data when the user feels stress. This function can make the system distinguish between the effects from physical activities and the effects from psychological stress. As for the pulse sensor, we will study a ring-type sensor.

Secondly, the evaluation method based on the hearing has limitations. We used 90 seconds sample data and Likert scale. However, users should wear the sensor and devices for a several days or several weeks in order to do the evaluation with high precision. After that, we have to compare the stress reduction effects between the users not using this system and the users using it. For example, we should compare the following condition; the illuminative effects with 1/f noise or without 1/f noise; the system with the illuminative effects or the system without them; the direct representation with stress information or no representation, and so on. These long term experiments will need unwiring of sensors and downsizing and power saving of batteries.

VII. CONCLUSION

This paper described the design of aequorin which is the system for measurement and reduction of the user's stress for a day. This system adopted two approaches for stress reduction with the stress data which is composed of stress values and each time codes for a day obtained by the user wearing the wearable device; one is the indirect presentation of the stress information as biofeedback in which the system illuminates the LED lights with 1/f noise according to the amount of stress, and the other is the direct presentation of the stress information as biofeedback on the display. We had a hearing to validate these two approaches, and we found that the researcher group and the businessperson group got the opposite results. It means that the researcher group was positive to the illuminative effects and the direct representation of stress, whereas the businessperson group was negative to both approaches. In the future, we will develop a function to make an annotation to log data while feeling stress and a ring type wireless pulse sensor and do several mid-term or long-term user experiments.

ACKNOWLEDGMENT

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