A Multi-Modal Intelligent System for Biofeedback Interactions

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***Abstract*—Biofeedback is an emerging technology being used as a legitimate medical technique for several medical issues such as heart problems, pain, stress, depression, among others. This paper introduces the Multi-Modal Intelligent System for Biofeedback Interactions (MMISBI), an interactive and intelligent biofeedback system using an interactive mirror to facilitate and enhance the user's awareness of various physiological functions using biomedical sensors in real-time. The system comprises different biofeedback sensors that collect physiological features; the system also provides intuitive, intelligent, and adaptive user interfaces that promote a natural communication between the user and the biofeedback system. The Ambient Intelligence (AmI) technology is incorporated in the system to provide means for biofeedback responses. The proposed conceptual system is been evaluated by 15 subjects and the results are very stimulating. Ninety percent (90%) of the subjects confirmed that the system is beneficial, deployable, and affordable for personal use. On the other hand, 30% of the subjects have indicated that privacy is the resisting issue for the wide deployment of the system.**

***Index Terms*—intelligent and adaptive interfaces, biofeedback, ambient intelligence, smart mirror.**

I. INTRODUCTION

Biofeedback is an important and increasingly accepted method for preventive health care and alternative medicine [1]. According to the Mayo clinic (the world's largest integrated medical center providing comprehensive diagnosis and treatment in all medical and surgical specialties), biofeedback is a complementary and alternative medicine technique for treating more than 100 illnesses [2]. Early biofeedback systems were clinical, wherein with the help of a trained therapist, an individual could learn to control specific physiological functions by changing the thoughts and perceptions that produce them [3]. Today, biofeedback is the technology by which individuals can become aware of their various physiological functions using biomedical sensors, in order to manipulate those physiological functions with the aid of computer systems (such as using relaxation techniques) [4].

Meanwhile, Ambient Intelligence (AmI) is another promising technology that is witnessing significant attention in both academia and industry [5]. AmI refers to electronic environments that are sensitive and responsive to the presence of people [5]. An AmI system reads the state of the user's environment using sensors, makes reasoned judgments about the collected data using a variety of intelligence techniques, and acts upon the environment using various actuation technologies. There are many applications in which AmI can impact our lives, including in homes (such as smart homes), health monitoring and assistance, hospitals, transportation, emergency preparedness and services, education, and workspace developments [6]. One particular promising application for AmI technology is in health monitoring and biofeedback.

The combination of AmI technologies and biofeedback provides immense potential for enhancing medical healthcare applications such as self-monitoring, remote patient monitoring and counseling, among others. In this paper, we strive to design an interactive and intelligent mirror system that combines AmI with biofeedback to enhance the users' awareness of their physiological functions and to ultimately provide a fitting health-aware and responsive environment. The proposed MMISBI system uses an interactive mirror to interface the physiological functions in real-time to the user, and provides the means for proportional biofeedback responses.

The rest of the paper is arranged as follows: section II provides an insight into work relating to biofeedback systems and interactive interfaces; in section III, we introduce the proposed system and highlight its comprising components and merits; section IV presents a feasibility study for the system and discusses the derived results; finally, section V concludes the paper and provides perspectives for future work.

II. RELATED WORK

The multi-modal intelligent system for biofeedback interaction facilitates the awareness of the users' health status to maintain their well-being. Therefore, the system attempts to build a comprehensive biofeedback system by providing knowledge and analysis of the users' health, and then responding with a personalized feedback.

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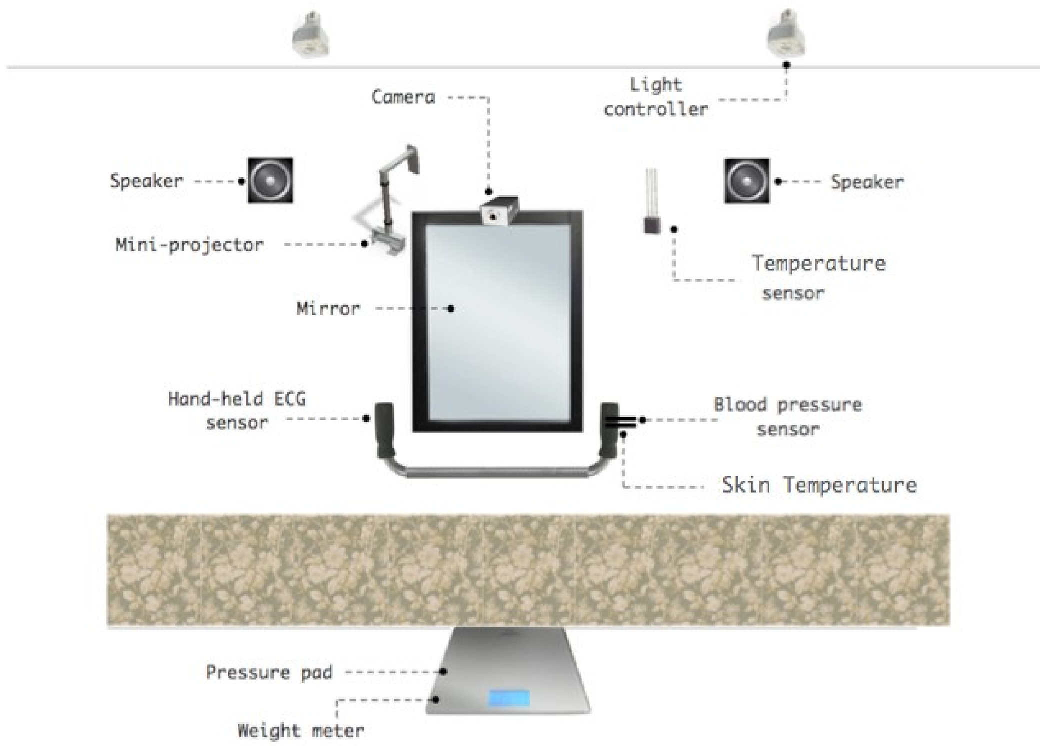

Figure 1: A design overview of the multi-modal intelligent system for Biofeedback Interactions.

In the following paragraphs, we highlight some related research and projects that target building a sensory system for biofeedback, and health monitoring in an AmI environment.

Ceccaroni and Verdaguer [10] designed an interactive mirror as the main interface to provide interactive television, a personalized set of multimedia displays such as weather forecast, reminders, and personal motivation content. Aside from the conceptual design of their model, some functionalities were simulated services rather than real implementation. Onur Asan et al. [11] proposed another interactive mirror in the bathroom to allow the user to perform different activities such as checking emails, weather forecast, or daily schedule.

Phillips Research HomeLab [9] tried to build an intelligent bathroom using an interactive mirror. The mirror was to be used to display visual output resulting from context-aware recognition of the bathroom environment. For instance, the mirror would have displayed the weather forecast or traffic information during regular activities like shaving. In addition, the mirror would act as a weight coach application to take the users through their latest weight losing/gaining progress. Using the mirror, children could enjoy watching a cartoon while brushing their teeth.

There are many proposed systems for monitoring ECG signal using wired and wireless sensors [15]. For instance, Fensli el al. [12] proposed convenient electrodes for cardiac arrhythmias monitoring. E. Jovanov el al. [13] designed a wireless body sensor network for ECG and motion monitoring. Based on the heart and body activities, the system generates warnings and feedback that help during the subject's rehabilitation sessions [13]. The stress level is one of the important patterns to extract from ECG signals in by measuring the heart rate variability (HRV) [14]. Moreover, a pulse sensor is also useful to measure the stress level and can give solid results for a biofeedback device. As an example, S. Tokuhisa [17] designed a biofeedback chair using a pulse sensor attached to the ear lobe.

Biofeedback information is widely used for medical training to give the subjects greater control of their bodies [17] [18]. G. Liu et al. [16] proposed a wearable biofeedback belt to monitor the respiration rate. The goal of giving respiration biofeedback is to train the subjects by displaying in real-time their immediate respiration rhythm.

In order to comprehensively evaluate the health status of the users to generate the appropriate biofeedback, the proposed MMISBI system records the physiological parameters in a way that does not disturb a person's daily life. In essence, the measurement can take between 3 to 5 minutes per day to analyze the user's health condition avoiding any attached wireless sensors and giving the freedom to roam freely at home, the gym, or at work.

III. Proposed System

A. System Overview

Biofeedback systems are designed to help people understand and react to their bodies' health conditions by monitoring their physiological functions regularly, thus improving awareness of their health status. Biofeedback systems include different models that collect physiological sensory data and provide different means of response techniques. In this paper, we propose the MMISBI, a system using intuitive, intelligent, and adaptive user interfaces that could facilitate natural communication between the users and the biofeedback system, thus providing responses to the users' environment. The means of interaction for the users should be convenient so that they may have access to different biofeedback services. Specifically, we propose an interactive mirror that displays, in real-time, the correlation of biofeedback information, and highlights important events about the subjects' health. Figure 1 shows an overview of the proposed system using an interactive mirror in an AmI environment. The system is composed of biofeedback sensors, pressure pad, camera, decision support agent (software), and a set of response interfaces.

The proposed system provides user-friendly physiological measurement interfaces. Those interfaces are capable of recognizing and responding to the user's physiological parameters. The interactive mirror along with the different biomedical sensory interfaces build up a multi-modal intelligent system for biofeedback. The system collects different body physiological parameters such as ECG, blood pressure, skin temperature, as well as body weight. Moreover, the system integrates other parameters such as room temperature and humidity level. All the collected data are then integrated to generate responses to the user's health status.

B. System Components

The main components that comprise the proposed biofeedback system are shown in Figure 2. The following sub-sections describe each component and its functionality.

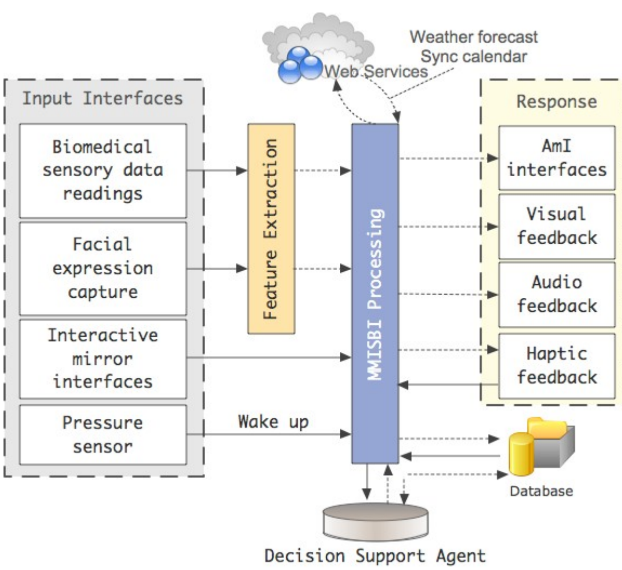

Figure 2: The design architecture of the proposed multi-modal intelligent system for biofeedback interactions (MMISBI)

1) Input Interfaces

The input interfaces are devices used to acquire data about the user and/or the environment. There are several components of the input interfaces namely biofeedback sensors, an interactive mirror, and audiovisual multimedia interfaces. The followings are brief descriptions of each.

1.1) Biofeedback Sensors

The system uses different biomedical sensory devices to read information about the human physiological state in order to enhance the subject's awareness of their physiological condition. There are several physiological parameters that are included in the system:

- *A hand-held ECG:* the sensor is used to provide the system with the ECG biofeedback information. The resulted sensory data are used to monitor different heart activity patterns within the context of the user's health condition. Measuring the stress level is one of the objectives of recording the ECG signal. Also, not only does the system try to measure the stress level but also attempts to accommodate different response techniques in order to reduce it through different AmI response interfaces.
- *Blood Pressure:* A blood pressure sensor measures the systemic arterial pressure measured at the user's finger [19]. The sensor detects the blood flow, and thus is able to detect the blood volume changes on the finger.
- *Skin Temperature:* A hand-based skin sensor measures the palm temperature of the user. Many commercial available sensors are now capable to measure the temperature and humidity of the skin. Such meters increase the system's understanding of the user's health condition.
- *Weight Meter:* The weight meter is used to monitor the user's weight continuously. The readings obtained from the meter are analyzed to help those who are trying to lose weight, and recommend daily workout exercises and durations.

1.2) Interactive Mirror

The interactive mirror is an input device that promotes intuitive and natural interactions with the user. The user uses his/her finger to navigate through the biofeedback information that are collected and displayed onto the mirror in real-time. The interactive mirror uses proximity sensors located along the edge of the mirror to measure the position of the user finger and pass this information to the computer to control the mouse movement and actions.

1.3) Audiovisual Interfaces

Audiovisual interfaces include both auditory and visual sensors (such as microphones and video cameras) that have been widely used for many medical applications, especially for elderly care and Tele-diagnosis. The auditory input interfaces enable controlling the system via voice commands. Additionally, the voice of the subject can be captured and analyzed against several health concerns. On the other hand, the video camera is used for user identification and verification. The system uses the camera information to perform facial recognition to authenticate the user, as well as for affective computing (to detect the user's emotional state).

2) Response Interfaces

The MMISBI applies different response mechanisms and can act as a subject advisory and coaching program. In particular, the interfaces will adapt to the user's current health state via an effective user model created for each individual subject (which would result in personalized responses). For example, the biofeedback system monitors the subject's weight and finds that the subject gained a few pounds in the last two weeks. As a result, the system will suggest different exercises and the duration of each in order to shed those pounds. Another scenario is that of the stress management monitoring interfaces, where the system responses to the subject's stress level by adapting the lighting intensity of the room, playing a list of selected music, changing the room temperature, or suggesting a relaxation exercise.

2.1) AmI Interfaces

AmI interfaces are currently embedded in many objects in our living environment [20]. For this project, we were interested in including AmI controllers for the user's environment such as lights, music speakers, as well as room temperature. For instance, the light controller controls the light intensity for multiple lights. Moreover, the temperature sensor captures the room temperature that is required to change according to the physiological functions. Accordingly, we build a smart environment adapted to the biofeedback information.

2.2) Visual Interfaces

A mini-projector is used to display important messages, reminders, or measurement results. It is one interaction interface medium that is used in our biofeedback response system to remind the user to take a prescribed medication, to display the level of workout the user needs to do, or to provide a short summary of the obtained results.

2.3) Audio Interfaces

The MMISBI system uses audio speakers to generate audio biofeedback responses. Particularly, the speakers can play different music categories based on the system analysis of the user's present condition. For instance, if the system detects that the user's stress level is higher than usual, a list of relaxation music can be played to bring the user back to a relaxed state.

2.4) Haptics Interfaces

The system also integrates the use of gesture-based interaction technology, so that it becomes intuitive to use and therefore feels natural to the user. For example, there have been extensive studies on using vibro-tactile technology as a display mechanism for blind or visually impaired users [7].

3) MMISBI Management Center

The MMISBI management center provides the algorithms and processing tools to derive useful conclusions from the collected biofeedback information, and intelligent and adaptive means to implement the proper response techniques. Furthermore, the intelligent interface can learn about the subject's lifestyle and adapt the interaction style/mode accordingly. The success of the whole biofeedback system is highly dependent on the development of intelligent and intuitive interfaces that are aware of the user's needs and intentions. Here, the pressure pad is used to activate the system and wake up the entire sensory network available, triggering the start for collecting the sensory data. The pad will be placed in front of the mirror in a way to ensure the user will have to step on it in order to look at himself/herself in the mirror.

3.1) Facial expression recognition

Facial expression recognition is also a part of the system to analyze the face of the person standing in front of the mirror. The camera will be used to capture a list of facial expressions. Facial recognition will be used to authenticate and authorize the user to use the system and to enforce information privacy.

4) Decision Support Agent and Database

Different users have different personalities [8]; likewise they prefer different response techniques to their emotions and health conditions. Therefore, the system generates user-dependent biofeedback responses. An algorithm is designed to learn the user preferences and personality, and generates a list of affective information that will be used to generate a biofeedback response. For instance, the system considers the user's age, gender, favorite music artist, lifestyle, work schedule, and other parameters that will help to personalize the services. To draw a scenario, a 35-year-old man uses the smart mirror system at home right after he returns from work; the system finds his stress level to be beyond what is normal; he has an important dinner appointment in three hours that is already indicated in his synchronized schedule. After analyzing the collected information, the system suggests that the user have a nap for an hour or go for a 15-minute walk, or have a cup of green tea while listening to a selected list of his favorite music in order to reduce and handle the stress.

The decision support Agent retrieves the user information from the system database where the user's latest significant events, sensory data, and preferences are stored. The database also provides the recorded events along with the progressive measurements to the MMISBI processing component to take the applicable biofeedback response, and to generate the suitable progress report.

IV. FEASIBILITY STUDY

Fifteen (15) subjects belonging to different age groups participated in the feasibility study of the proposed system (8 male and 7 female). The subjects were introduced to the proposed system and then asked to fill in a questionnaire (the 4 most relevant questions are listed in Table 1). Eighty percent (80%) of the subjects agreed that the system is beneficial to promote public health and wellbeing.

Furthermore, 74% of the subjects believed that the proposed system does not compromise their privacy. A summary of the results for the four questions in Table 1 is shown in Figure 3.

Table 1: Key questions in the feasibility study questionnaire

Q1	To what extent do you think the system is beneficial to promote public health and wellbeing?
Q2	To what extent do you think the proposed system is deployable within the few coming years?
Q3	To what extent, if any, do you think the proposed system compromises your personal privacy?
Q4	Would you prefer to get a copy of your biofeedback data captured by the system via, for example, communication with your mobile phone?

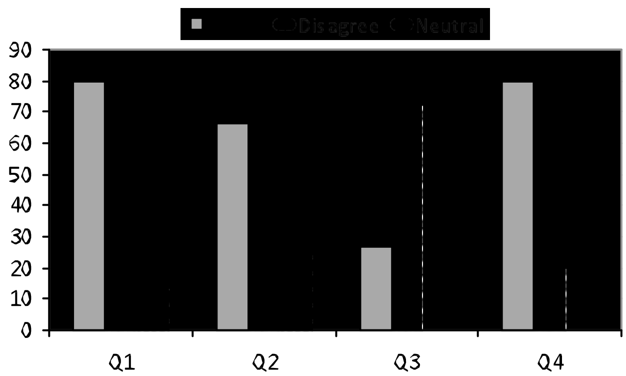

Figure 3: Results for the 4 questions in Table 1.

After debriefing, interesting observations were derived. First, several subjects suggested that the system should communicate the captured data to the subjects using either their cell phones or via printouts. Others suggested that the system use other biofeedback sensors such as a blood glucose sensor for diabetic patients. Finally, a few subjects suggested that the biofeedback data presented to the users should not be overwhelming, and should be easy to read and to understand.

V. CONCLUSION

In this paper, we have proposed a biofeedback system that uses an interactive mirror to facilitate the interaction between the user and the system. The objective is to enhance the user's awareness of various physiological functions using biomedical sensors in real-time. The feasibility test has confirmed the ability of the system to promote the wellbeing of humans. We will incorporate the feedback in the implementation of the system prototype using the above-mentioned sensors and perform a series of experimental studies to confirm our findings in this paper. Finally, we are open to use other types of biofeedback sensors as the research progresses. In order to personalize the services provided by the proposed system, we will investigate different authentication mechanisms that will enable identification and creation of personal profiles. The authentication will be used only to change personal preferences or access the history of the collected biomedical data. The mechanism should assure the privacy protection of the users information while not disturbing the users to authenticate themselves each time they stand up in front of the mirror.

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