EREC-II in Use – Studies on Usability and Suitability of a Sensor System for Affect Detection and Human Performance Monitoring

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Abstract. Interest in emotion detection is increasing significantly. For research and development in the field of Affective Computing, in smart environments, but also for reliable non-lab medical and psychological studies or human performance monitoring, robust technologies are needed for detecting evidence of emotions in persons under everyday conditions. This paper reports on evaluation studies of the EREC-II sensor system for acquisition of emotion-related physiological parameters. The system has been developed with a focus on easy handling, robustness, and reliability. Two sets of studies have been performed covering 4 different application fields: medical, human performance in sports, driver assistance, and multimodal affect sensing. Results show that the different application fields pose different requirements mainly on the user interface, while the hardware for sensing and processing the data proved to be in an acceptable state for use in different research domains.

Keywords: Physiology sensors, Emotion detection, Evaluation, Multimodal affect sensing, Driver assistance, Human performance, Cognitive load, Medical treatment, Peat baths

1 Introduction

Emotions are currently discovered by numerous researchers in different fields of research and are regarded to be a potential key to many problems unsolved or observations not understood up to now. This includes designers of physical or artificial objects, human-computer interaction researchers, interface designers, human-human communication specialists, phone service companies, marketing

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specialists, therapists for mental or physical discomforts or illnesses or, more general, people concerned about the well-being of other people. But also in the traditionally emotion-aware sciences, emotions get renewed attention due to the increased availability of novel technologies in this field. Among the multitude of possibilities for measuring emotion, cf. [11], the number of exploitable emotion channels for unobtrusive emotion monitoring is small. When mobile or at least non-lab acquisition of emotion-related physiological parameters is needed, the choices are very limited.

While facial expressions are one of the most obvious manifestations of emotions [8], their automatic detection is still a challenge (see [6]), although some progress has been made in recent years [1, 9]. Problems arise especially when the observed person moves about freely, since facial features can only be observed when the person is facing a camera. A similar problem arises with speech analysis, which requires a fairly constant distance between microphone and speaker (see [6]). Gesture and body movement/posture also contain signs of emotions, but still are not sufficiently enough investigated to provide for robust emotion recognition. Emotion-related changes of physiological parameters have been studied for a long time (e.g. [3, 4, 7, 10, 14]) and thereby presently can be considered to be the most investigated and best understood indicators of emotion. It is hence assumed that physiology sensors can become a good and reliable source on emotion-related data of a user, despite their disadvantage of needing physical contact.

There are various commercial systems available for measuring emotion-related peripheral physiological parameters, such as Thought Technologies' Procomp family, Mindmedia's Nexus device, Schuhfried's Biofeedback 2000 x-pert, or BodyMedia's SenseWear system. However, those systems have been developed for medical or psychological studies which usually take place in fixed lab environments, or for sportsmen who have lower requirements on time resolution and availability of the data than most HCI applications have. Having realised the shortcomings of commercial systems, the scientific community also developed prototypical sensor systems for unobtrusive measuring physiological states. These are mainly feasibility studies with in part very interesting sensor placements and application ideas [2, 12, 15, 16].

This paper reports on evaluation studies of one of those. The EREC sensor system developed at Fraunhofer IGD Rostock allows to wirelessly measure heart rate, skin conductance, and skin temperature. The evaluations have been performed independently by two groups and covered 4 different application fields. In a medical environment, the emotion-related physiological reactions on peat baths were examined. The second study investigated human performance in sports, and a third dealt with driver assistance issues. The fourth report gives account on inclusion of the EREC system into a multimodal affective sensing approach.

Section 2 describes the improvements of the used versions of the system compared to the initial system described in [15]. This is followed by the evaluation reports in Section 3. A summary and outlook in Section 4 conclude the paper.

2 System Overview of the EREC-II Sensor System

The EREC system consists of two parts. The sensor unit uses a glove to host the sensing elements for skin resistance and skin temperature. It also collects heart rate data from a Polar heart rate chest belt and measures the environmental air temperature. The base unit is wirelessly connected to the sensor unit, receives the pre-validated sensor data, evaluates them, stores them on local memory and/or sends the evaluated data to a processing host. In the following, more details are given in comparison to the EREC-I system described in [15]:

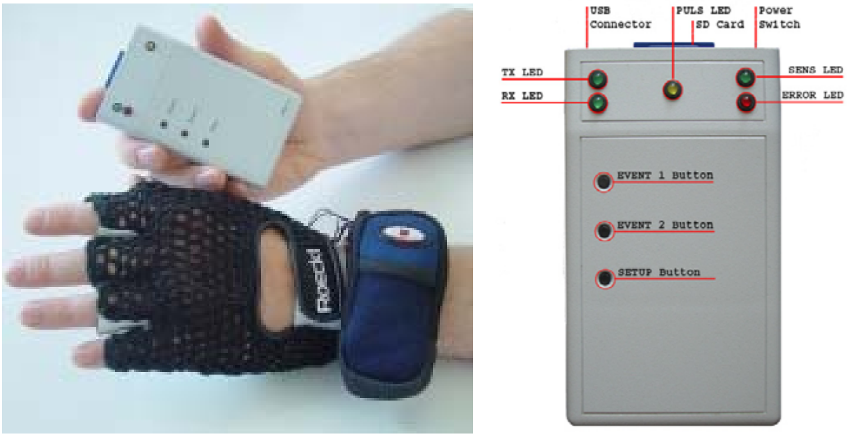
(a)  (b)

Fig. 1. (a) In EREC-II the sensing circuitry is stored in a wrist pocket, making the glove lighter and improving ventilation. (b) Base unit of EREC-IIb.

2.1 EREC-II Sensor Unit

The sensor unit is functionally identical to that of EREC-I, with small changes to the circuit layout. The sensing elements are fixed now on a cycling glove. As shown in Figure 1(a), the sensor circuitry is not integrated in the glove, but put into a small wrist pocket. Connection between sensing elements and circuitry is established by a thin cable and a PS/2 shaped socket. As with EREC-I, the skin conductivity sensor is implemented two-fold. The skin temperature is taken at two different positions as well and integrated in one sensor, leading to higher accuracy and higher resolution. Also in the sensor unit, the ambient air temperature near the device is measured as already done with EREC-I. Skin temperature as well as skin conductivity are sampled 20 times per second each. Heart rate is still measured using Polar technology.

Data are sent out by the heart rate sensor immediately after a beat has been detected. All collected data are immediately digitized and assessed for sensor failure as was done in the EREC-I system. Based on the evaluation results, output data are prepared, wrapped into the EREC protocol and fitted with a CRC check sum. The data are then sent out by the integrated ISM-band transmitter.

2.2 EREC-II Base Unit

The base unit has undergone a major re-design (see Figure 1(b)). It has now a pocket-size case, no display, and uses an SD card for storing data permanently. There is still the possibility of a serial connection to a PC. The user interface consists of light emitting diodes (LEDs) for communicating different sensor and system states, and push buttons for the user to mark special events. As with EREC-I, sensor data are received from the sensor unit, transport errors are assessed (CRC), and reliability checks are performed each time new data are received. Validated data are sent out immediately to a connected PC and stored on the memory card at an average rate of 5 Hz. All data are made available in engineering units. The skin temperature is represented in degree Celsius with a resolution of 0.01°C. The skin resistance is measured in kilo ohms with a resolution of 300 kilo ohms. The heart rate is measured in beats per minute with a resolution of 1 beat per minute (bpm).

3 Test Implementations and Evaluation Studies

Over time, different versions of the EREC-II system have been developed and tested in field tests. They differ in slight modifications of the hardware in the base unit as well as in the software running on the base unit's microcontroller. Four evaluation studies of the EREC-II system have been performed independently by two groups in Germany and Australia, respectively. The studies covered the application fields medical, human performance in sports, driver assistance, and multimodal affect sensing. All studies were real-world studies with the main goal in the particular field. Evaluating the sensor system was a by-product kindly performed by or with the local staff. This section describes shortly the particulars of the different versions and, in more detail, the studies and their evaluation results.

3.1 EREC-IIa

System particulars. EREC-IIa is the first version of the EREC-II series. Serial communication to a PC can be established by a RS232 connection. However, the SUB-D socket for the serial connection has been replaced by a miniUSB socket to save space in both the casing and on the printed circuit board. It can also be seen as a step towards a USB connection between PC and base unit. Data are stored on a SD card. The same data format and writing procedure is used as with the EREC-I system. Still, the memory card needs to be pre-formatted and has to contain an empty file which is then filled by the controller with sensor data in a proprietary file format.

The user interface of the device consists of 3 LEDs which use simple flash codes to signal different states. For instance, slow flashing of the sensor LED indicates that all sensors are working correctly, while fast flashing indicates failure of at least one sensor, with increasing flash frequency for an increasing number of failing sensors. This approach allows to use a few LEDs to deliver much information, which is beneficial for battery life. Two push buttons allow for simple user input, for instance, to mark special events. EREC-IIa can be seen in figure 1.

Evaluation. This study was performed over a period of 8 weeks by the Chair of Complementary Medicine of the University of Rostock, Germany, at the rehabilitation clinic “Moorbad Bad Doberan” (Bad Doberan, Germany) which has broad and long-standing experience in the application of peat in the treatment of various diseases.

Physiological response to peat baths

Hot peat is used for various medical indications such as relief of pain and general improvement of chronic skeletal and rheumatic diseases as well as gynaecological and dermatological problems. So far only subjective qualitative and unsystematic reports on the emotional reactions during and after a peat bath exist. Therefore, the study has been performed to investigate emotion-related physiological reactions of healthy persons in a single session of a peat bath and to obtain quantified evidence for their changes during this session. During the study, peat baths were performed as usual: 20 minutes peat bath (40.5°C), warm shower, and 20 minutes of rest. For study purposes, an additional 10 minutes for answering questionnaires were added at the beginning and the end of the bathing session. Thereby one session lasted for about one hour.

Electro-cardiographic (ECG) data were collected by a Holter monitor, and skin temperature and skin resistance measurements where gathered with the EREC-IIa system. The latter also recorded the room temperature near the sensors. At the beginning of the session, the subject put on the sensor glove and the ECG electrodes were fitted on the upper side of the left and right distal forearms. During the peat bath, only the subject’s head and the distal forearms were outside the peat, with the hands resting on a handrest. Thereby, a fairly comfortable position was achieved for the test person.

Generally, all test persons felt comfortable and found the glove easy to put on and off. The light, meshed fabric on the top side of the glove allowed for good air ventilation around the hand and, hence, avoided a local increase of the temperature caused by the glove. However, the leather part at the palm was fairly stiff which made it difficult for subjects with thin fingers to maintain proper contact between electrodes and skin. This problem could be answered by either providing gloves in different sizes, or by using gloves of a material which is thinner and more elastic than this actual model.

We also experienced bad skin conductance readings at the beginning of the session with most subjects. One assumption is that this may be due to very dry skin of the particular test persons, which changed over time during the session. In this case, the sensitivity of the sensing circuitry should be adaptable or even self-adapting to the actual conditions. Another explanation would be that the material of the electrodes is not suitable for continuous use over several weeks. Being exposed to human sweat, a chemically aggressive substance, the metallic surface of the electrodes is subject to corrosion which leads to deterioration of sensing results. In this case, a chemically more resistant material should be chosen for the electrodes, or other techniques for measuring electro dermal activity (EDA) should be found.

The data collection unit is very neat and handy. Having LEDs indicating the system being operational and showing any problems that might occur is nice and assuring. However, just 2 flashing LEDs for indicating many different states is sub-optimal in our view. Even more problematic was the use of the red LED. It was used for indicating SD card errors, sensor errors, bad wireless connection, and a warning on low battery status. This was not only difficult to memorize but also, as a consequence, led to the experimenter feeling helpless and fearful for the data each time the red light was on. We think that more LEDs would be beneficial, for instance one for each sensor type, one for battery life, and one for the quality of the wireless connection. The push buttons for indicating different states were very helpful as they allowed to mark events during the session which attention had to be paid to in the data evaluation. They could be handled easily and were safe from unintended use.

Storing the data on an exchangeable SD card is a very good idea and helps to perform several tests in a row without the need of saving data on a PC between sessions. However, preparation of the SD cards for use in the EREC-IIa system is not acceptable for the non-technical user. It required the experimenter to first format the SD card on the PC, and then to create an empty file of sufficient size on the SD card using a dedicated program. Particularly the need of calculating the size of the empty file caused extra stress since the experimenter was constantly worried that the size was not sufficiently big and valuable data being lost, while on the other hand a big file resulted in inconvenient long reading times in the EmoChart analyser. An improvement would be to let the EREC system create the files as needed, freeing the user from technical considerations and fears.

Finally, the idea of synchronized collection of EDA, skin temperature and room temperature data by use of a sensor glove is considered very useful as it provides a new and easy way to collect emotion-related time-synchronized physiological data.

3.2 EREC-IIb

System particulars. EREC-IIb has been developed based on first experiences with EREC-IIa. It now features a real USB connection for the serial communication to the PC using the virtual COM port mode to allow existing RS232-based software for online analysis of sensor data. The SD card still needs to be formatted before being inserted into the system, but the controller now creates itself files in the proprietary file format, one file per session. The user interface has been changed slightly by providing more LEDs and better interpretable flash codes but is otherwise identical to EREC-IIa.

Multimodal affective sensing approach. The NICTA Vision Science, Technology and Applications (VISTA) group is interested in measuring and analysing physiological sensor data from a perspective of monitoring human performance as well as improved human-computer interaction (HCI) in the long term. In the following, a brief overview of these activities is given, which are driven by both applications and general research issues. We believe that only a multimodal, multi-sensor approach can truly deliver the robustness required in real-world applications, and supplying computer systems with the capability to sense affective states is important for developing intelligent systems. In terms of modalities, our research is focussed on using audio, video, and physiological sensors.

In the audio modality, we use features such as fundamental frequency F0, energy, and speed of delivery to gain insights into evidence of affective states in spoken language. Recently, we proposed a new, more comprehensive model of affective communication and a set of ontologies which provide a rigorous way of researching affective communication [13]. In the video modality, we use active appearance models (AAM) to track the face of users and its facial features [5]. AAMs are a popular method for modelling the shape and texture of non-rigid objects (e.g. faces) using a low dimensional representation obtained from applying principle component analysis to a set of labelled video data. We combine AAMs with artificial neural networks to automatically recognise facial expressions. Finally, we use the EREC-II sensor glove system for measuring physiological responses related to affective states. Galvanic skin response, heart rate and skin temperature are of particular interest to us and these measures are all provided by the EREC-II system.

In our experience, both experimenters and test subjects find the glove system easy to use and comfortable to wear. From a user's point of view, the glove does not prevent a 'normal' use of the hand. The system being integrated into a glove has the advantage that it is very lightweight and that it is comfortable to wear even for longer periods of time. We found that having the sensor circuitry in a separate unit which is attached to the wrist is acceptable in many application areas, in particular when the wearer is sitting, for example, while working on a computer. However, for more mobile application scenarios, it would be advantageous to have a more compact unit that is integrated with the sensor glove. We experienced occasional problems with the heart rate sensor whose transmission was not always received by the sensor circuitry. We see potential for further improvements in terms of the reliability of the transmission in this area. Overall, we found the sensors to work reliably and the entire system to be robust and very useful in our applications, which we describe in the following.

Evaluation. EREC-IIb has been evaluated at the National ICT Australia (NICTA) Canberra Research Laboratory, Australia, who use the system since November 2006. The evaluation results stated here have been obtained over a period of 5 weeks in two different studies.

Human Performance Monitoring

In a joint project with the Australian Institute of Sports (AIS), Canberra, Australia, we investigate how state-of-the-art camera technology in the infrared range of the electro-magnetic spectrum can be used to measure performance indicators that were so far only accessible by physiological sensors. Near-infrared (NIR) cameras can be tuned to wavelengths specifically relevant to human haemoglobin, which is the carrier of oxygen in blood, so that haemoglobin levels can be measured in a non-invasive way. Similarly, far-infrared cameras (FIR) can visualise thermal energy emitted from an object, e.g. a human body. We use FIR cameras to measure the surface temperature of athletes, map these onto a 3D model of the athlete's body and determine the heat source using finite-element methods.

In this project, the EREC-II sensor glove system is used as a ground-truthing device because it allows to measure physiological parameters directly. In the experiments, an AIS athlete sits on a cycling ergometer during a training interval and data are recorded from the EREC-II system, the NIR and FIR cameras. During an analysis of the training interval, the performance indicators derived from the video data is compared with the data from the physiological sensors as well as data from blood samples. The test subjects in the experiments have found the EREC-II sensor glove comfortable to wear and reported no particular problem with it. Our goal is to develop a non-invasive measurement system that allows for an easy, non-invasive way of measuring an athlete's performance indicators. For future versions of the EREC system, we would like to see an optional pulse oximeter (SpO2 sensor) being integrated. The project is currently in the experimental phase.

Affective Sensing for Improved HCI
We also investigate multimodal HCI systems that are capable of sensing the affective state of a user and that monitor this state or take it into account in the actions of the HCI system. The application background here are driver assistance systems that aid the driver in their driving task. Vehicle drivers have to perform many cognitive tasks at the same time and one of the major sources for accidents is 'cognitive overload'. Another danger is driver drowsiness which is particularly relevant for long-distance and night-time driving.

In our experimental vehicle, we have placed cameras that look at both the road and surroundings outside the car as well as monitor the driver. While facial feature tracking and eye blink detection are one way of detecting drowsiness, we had no way of measuring physiological parameters before the EREC-II system was incorporated. Ultimately, one would like the sensors in the EREC-II system to be integrated into the steering wheel, rather than having to wear a sensor glove, but for an experimental vehicle the setup is acceptable. Measuring the heart rate, galvanic skin resistance and skin temperature give direct cues about the affective state of the driver and can be used to improve the reliability of drowsiness detection systems. The test subjects in our experiments found no problem in wearing the glove while driving. Current work in this project focuses on the integration of sensor data from the EREC-II system and video system in a multimodal system.

4 Summary and Outlook

This paper reported on design aspects and evaluation studies of the EREC-II system for measuring affect-related physiological parameters. The evaluations have been performed independently by two groups in Germany and Australia, respectively. The evaluations can be summarized as follows:

The design of the sensor system as consisting of a lightweight glove and a wrist pocket is fine. Particularly the meshed fabric at the top of the glove was rated very comfortable by all subjects. The palm side of the glove being made of leather has been experienced as pleasant by some subjects (sports), as acceptable by others (automobile and multimodal affect sensing), and as sub-optimal for persons with slim hands and fingers. The latter was mainly due to the material being too stiff to maintain proper contact to the skin.

For the electronics being put into a separate wrist pocket, it was acceptable for all applications. However, integration into the glove has been suggested by all studies. The system has been considered easy to use after a number of adjustments were made to the initial design. Particularly, the handling of the SD card and related file management have been a problem at first which could be alleviated in version IIb. Occasional problems occurred with the pulse sensor which could be alleviated by changing the placement of the pulse receiver away from the battery pack.

The system proved to be robust and reliable. An experienced lack of confidence in the reliability of the system was due to sub-optimal usage of LEDs representing the system and sensor states.

Based on these results, the following improvements are envisioned for the next development phase:

- Other material for the glove will be sought and evaluated. Also, different sizes will be provided where needed. Integration of the electronics into the glove will be evaluated. Since processing electronics inside the glove will increase weight and stiffness of the glove as well as producing heat and hindering air circulation, this seems to be an option only for selected application fields.
- The heart rate detection needs to be improved. We will investigate new ways here as well as look for ways to improve the currently used technology. Skin resistance electrodes will get a more resistant surface, for instance of silver/silver chloride as used with conventional medical devices. This will alleviate sensor fouling and lead to improved readings for EDA. Adaptation or even self-adaptation of skin resistance sensors to the actual range of measurement values is an issue also to be addressed in following versions.
- The user interface needs to be further improved. Particularly the usage of LEDs for indicating system states and sensor and communication errors needs to be separated. This will be addressed in the next version.

Concluding, it can be said that developing sensor systems for physiological parameters is a challenging undertaking. First, there proved to be huge inter-personal variations in the range of physiology readings, particularly for EDA. Second, different scenarios have different requirements on the design of the system, and common requirements are rated with different priorities by different user groups. It was also found that users in different research domains have a different understanding of what technology should do and is capable of doing, which also results in different requirements on the user interface of hard- and software.

We conclude that sensor systems for real-world applications need either be domain-specific, i.e. dedicated to an application field or even scenario, or very adaptable.

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