Real-Time Monitoring of Neural State in Assessing and Improving Software Developers' Productivity

Stevche Radevski*, Hideaki Hata*, Kenichi Matsumoto*
*Graduate School of Information Science
Nara Institute of Science and Technology, Nara, Japan 630-0101
Email: [stevche.radevski.sl1, hata, matumoto]@is.naist.jp

***Abstract*—Productivity has always been considered a crucial factor for the success of any business, and the same applies to software development. As a result of software development being almost entirely a cognitive task, problems in cognition highly correlate to problems in productivity. Being able to monitor the neural state of developers in real-time can aid in detecting and handling such cognitive problems before they occur and cause any damage. This also means aiding software developers in taking sufficient breaks, assigning tasks appropriate to their knowledge level, managing deadlines and stress, and so on.**

In this paper we propose Emendo - a conceptual system for continuous monitoring of developers' neural state using an off-the-shelf device. Furthermore, we provide a pilot study on the usability and feasibility of the proposed device for continuous monitoring. We also provide a short discussion of the ethical and acceptance issues of monitoring systems. Our goal is to introduce the possibility of a neural state monitoring and its potential benefits to the research community, hopefully attracting more researchers in this research field.

I. Introduction

Nowadays, nearly every piece of electronics has some kind of software, and the emergence of new technology and the development of smart devices will only increase the demand for it. The problem that arises with the increase of demand for software is the scarcity of software developers, thus emphasising the importance of productivity of the ones that are available to meet the demand. What the software engineering community has concentrated on in the past is mostly creating tools and methodologies to increase productivity, paying little to no attention on the software developers themselves. Lately, there has been an increase in research in human factors, giving rise to a new perspective on performance and productivity of software developers. Continuously monitoring the neural state of software developers can take this perspective of productivity a step further. Software development, being mostly cognitive and relatively non-repetitive task, is a perfect fit for such neural analysis and monitoring.

Past research on brain monitoring has focused more on detecting various neural states during critical situations (driving, air traffic control, military), successfully detecting workload (eg. [1], [2]), fatigue (eg. [3], [4]), vigilance and drowsiness (eg. [5]) using an EEG device. Recently, intriguing research has also been done in software engineering on task difficulty assessment [6], understanding of source code [7], and workload detection [8], yet it is still in the beginning phases, with limited application.

The main drawback with research related to neural monitoring so far is that the devices used are not off-the-shelf products or require expertise to set up [1]–[5], [8], or the device lacked a significant number of sensors for monitoring purposes, such as the NeuroSky for EEG monitoring [6], making it difficult to move the research findings to the workspace. To the best of our knowledge, there has not been a system for continuous neural monitoring that is easily applicable in a real-world working environment with satisfying accuracy. Therefore, in this paper we provide:

- A short introduction of the technology and techniques required for developing a neural monitoring system;
- Emendo - a conceptual system for continuous neural state monitoring that is feasible to be utilized in a real-world working environment, using a potentially applicable off-the-shelf device;
- A pilot study on the usability and feasibility of the proposed device;
- Short discussion about the acceptance and ethical problems of monitoring systems.

Furthermore, in the beginning stages of Emendo we have decided to use only EEG data in order to make it easily applicable to the workspace and to reduce complexity, even though additional metrics may aid in the precision of detecting various neural states. In the more advanced stages of our research, we intend to introduce other psycho-physiological metrics that are unobtrusive and can provide additional information.

II. Technical Details

A. EEG for Neural Monitoring

Electroencephalography (EEG) is considered as a non-invasive, safe procedure that captures electrical activity from the brain, and. It has successfully been used for Brain Computer Interfaces [9] for several decades in various ways. Analysis is based on using the various features EEG contains, such as wave frequency, amplitude, shape, and so on, to detect a certain pattern in the data, classify it, and use the classified signal as input, or as a measurement metric.

The positive side and reason for choosing EEG for neural monitoring is that it has high temporal resolution, and it carries a lot of data that can potentially be used to detect the present mental state of a subject. The downside of EEG signals is the sensitivity to noise, such as movements, eye blinks, heartbeats, etc. Fortunately, most of the noise can be successfully detected and removed, leaving the researcher with relatively clean data. There is a large body of knowledge on noise removal and neural artifact detection as a result of the frequent usage of EEG devices in the field of Brain-Computer Interfaces.

B. Machine Learning

Machine learning is the main part in detection of neural states, and it consists of 2 phases: Calibration (acquiring training data and tuning the classifiers), and Usage (using the classifiers to recognize mental states) [10]. Initially, features are being extracted (such as frequency, band power, etc.), and then classified as one of the pre-determined neural states. Afterwards, such classifiers are used to detect the various neural states. This kind of analysis has been used for a long time in Brain-Computer Interfaces, thus numerous algorithms and frameworks for doing such processing exist.

C. Emotiv EPOC+

Emotiv EPOC+ is a commercial EEG device at an affordable price, which we propose for usage in Emendo at the time of writing of this paper. The device is based on saline soaked felt pad sensors, with 14 channels (AF3, AF4, F3, F4, FC5, FC6, F7, F8, T7, T8, P7, P8, O1, O2, based on 10-20 system), plus the left and right mastoids as references. In previous research, the motion sensors in Emotiv EPOC were used for noise reduction [11], and since Emotiv EPOC+ has 9-axis motion sensors (where Emotiv EPOC has 2-axis sensors), it provides the possibility for even better results in noise reduction. Emotiv EPOC+ also has wireless and Bluetooth connectivity, and a battery life of up to 12 hours. Furthermore, ready-made algorithms for detecting various facial expressions and emotions are provided along with the device's SDK.

Several studies have compared the performance and the validity of Emotiv EPOC (predecessor of EPOC+) [12]–[14], and all of them show promising results. Furthermore, Emotiv EPOC has been used in a number of BCI systems (eg. [15], [16]) with satisfying accuracy.

D. Emendo

Emendo, depicted in Fig. 1, starts with the developer setting up and mounting the EEG device at the beginning of the day. After the developer has set up and positioned the device properly, the monitoring starts automatically, and raw EEG is measured from each developer, that is then optionally stored in a database for future reference.

While monitoring, the raw EEG data goes through a noise reduction module. Next, unless calibrating the classifiers, a number of neural states are detected, such as stress, fatigue, workload, frustration, and so on. This is the part where additional research should be done, since there is little data on the patterns of such states, and how to detect them. When calibrating, we can feed the machine-learning database by storing large training data or pre-defined patterns characterizing individual neural states, or, optionally, by calibrating Emendo on individuals (which can be a time-consuming task, but will provide more precise detection).

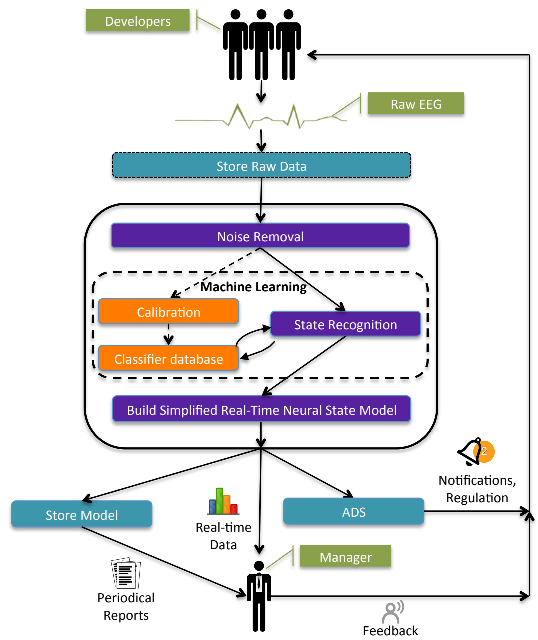

Fig. 1. Emendo

Next, a simplified real-time neural state model is created, so that the data can be presented in a quantifiable form. This model can then be: stored in a database for various analysis and periodical reports; shown to the manager (and optionally to the developer himself, but we decided to leave it out because it may be too distracting for the developer) in real-time, thus allowing the manager to give feedback to developers; used in the automated decision system (ADS) in order to send notifications to developers, assign tasks, etc. By design, the developers are allowed to do any kind of movement freely. As soon as the developers leave the workspace, the monitoring may be turned off using the motion sensors from the Emotiv EPOC+ device to not saturate the results, thus not requiring to even remove the device from their head when moving around the office or even outside of it.

There are numerous ways how Emendo can be used, so only few will be mentioned. Some of those are: task assignment, notifying when a developer cannot cope with the task assigned, optimizing breaks and working time, eliminating time-on-task effect, measuring efficiency, detecting if the developer is getting frustrated when working on a specific task, managing stress, and so on. Also, there is a possibility to generate weekly or monthly reports of developers' neural state throughout the period, calculate regressions, and so on, which can offer an opportunity to reflect on the procedures used in the company and potentially optimize the whole development process. Also, various data mining techniques can be applied on the data from within the company or from a 3-rd party, offering an opportunity for a new area of research.

III. Hardware Feasibility and Usability Pilot Study

In order to test if wearing an EEG device (Emotiv EPOC+ in particular) on a daily basis is feasible and it does not cause any problems to the developers, we conducted a pilot study with 6 subjects, where each subject wore the EEG device for an entire working day (around 8 hours).

A. Participants

Six individuals (all male) from the Nara Institute of Science and Technology's Software Engineering laboratory volunteered for this pilot study. The average age of the participant was 23.6 years (with minimum and maximum of 22 and 26 years respectively), all in a Master's or Doctoral course. None of the participants has ever been diagnosed with attention problems or ADHD symptoms, which may have affected how they perceive the usage of the device, and 4 of the participants were using glasses.

B. Experiment Process

In this experiment, one Emotiv EPOC and one Emotiv EPOC+ devices were used. The devices are exactly the same in their physical design, as well as in their set up procedure, where the only difference is the number of motion sensors, an additional Bluetooth connectivity, and option for higher sampling rate in the Emotiv EPOC+ device. Since we were testing usability and feasibility, and since all of the differences between the devices do not carry any importance for the purposes of our study, the devices were treated as equal.

Subjects were given the freedom to come to the laboratory, which also represents their working environment, at any given time previously arranged with the experimenter. The experiment started with the subjects answering a demographic questionnaire, followed by a short introduction of the experiment and its goal. Then, a short demonstration of how to set up and mount the device was given by the experimenter (moistening the felt pads, putting them on the device, etc). Subjects were then asked to set up the device on their own, starting from the beginning, and position the device properly on their heads. The software that is provided with the devices gives a map of which sensors are properly positioned and which are not, thus enabling the subjects to make slight adjustments to bring all the sensors in the proper position. Note that this was the first time the subjects have seen and used the device, so after a continuous usage the setup and positioning processes may become faster and easier. Following the proposed design of Emendo, the subjects were not required to do anything else aside from setting up, turning on, and mounting the device properly. The devices were connected to a computer that was several meters away from the subjects and no connectivity problems occurred (only Emotiv EPOC+ was tracked).

After a proper set up and positioning, the subjects wore the device continuously for an average of 7 hours and 38 minutes (with minimum and maximum of 7 hours 6 minutes and 8 hours 6 minutes respectively) during the day, doing their work as normal. The subjects were asked not to take off the device during the entire time, but were allowed to freely move around (going out for lunch, taking breaks). At the end of the day, the subjects were asked to fill out a questionnaire regarding the experiences using the device.

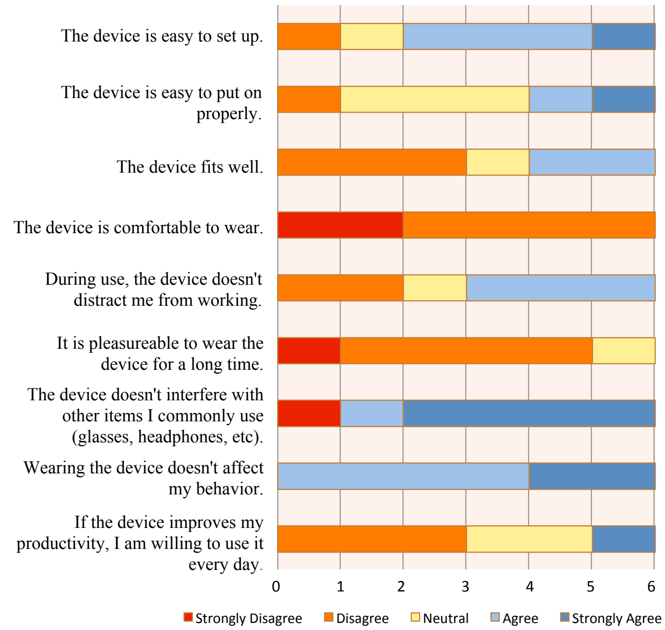

Fig. 2. Questionairre Results

C. Results

Most of the questions in the questionnaire were based on Likert scale, on a range from 1 (strongly disagree) to 5 (strongly agree). The results from these questions, as well as the questions themselves, are summarized in Fig. 2. Additionally, on the question about which task from the set up phase was the most difficult, all 6 subject answered that proper positioning of the device was the most difficult task to do. We also asked for any additional comments the participants may have had, and, in summary, every participant wrote almost the same thing: There are comfortability problems while using the device, and that after few hours of usage there was slight pain from the tightness of the device.

Furthermore, we also measured some other details that are important for daily usage of an EEG device. 1 hour of recording equals to around 25MB of memory space, including all sensor data, motion sensor data, and contact quality for each sensor, at a sampling rate of 128. In case the device goes out of Wi-Fi range, as soon as the device is back in range, it is automatically detected and the recording is automatically resumed. It took the participants 8.23 minutes on average (5.38 minimum, 11.54 maximum) to set up and position the device. The battery did not drop below 30% while recording for any of the subjects (the battery was fully charged every time). Also, while the subjects were concentrated on their work and at their desks, there was little to no noise, so the signal was quite stable. Displacement of any of the sensors that required manual repositioning did not occur (only the Emotiv EPOC+ device was tracked). One problem that occurred with all participants is slow degradation of the connectivity quality of some of the sensors, as a result of drying of the felt pads after several hours of usage. Using a better saline solution for wetting the felt pads or using larger quantity of saline solution may potentially fix this problem. What is also important to note is that 4 of the participants had relatively long hair, which slightly interfered with the positioning of the device and it made it more difficult to properly position it.

IV. Acceptance and Ethical Problems

New technology, especially the one that is used for monitoring purposes, almost always has acceptance and ethical problems among the public. Monitoring in the workplace has been around for decades [17], raising many debates concerning the ethical and privacy issues of such systems. Even though these issues are outside the scope of this paper, addressing and acknowledging them is of crucial importance for successfully integrating Emendo in the workplace.

Whether we will allow a system like Emendo to get a negative image among its users or not, depends on the approach taken to integrate it into the workplace. Of utmost importance is, instead of hidden, forced integration of the system, the system to be completely transparent to employees, and employees should be the ones to decide whether to use the system so it gives them higher personal control [18]. As the Technology Acceptance Model (TAM) [19] suggests, employees should become aware of the benefits of such system in order to have better acceptance rate. Also, employees should feel a sense of freedom at the workplace even when wearing the device, instead of having a feeling of being constantly monitored and judged.

V. Discussion and Future Work

Being in the beginning phases of our research, it is still too early to bring any definitive conclusions about the exact benefits of Emendo, yet the potential is high. As mentioned earlier, related research has shown that measuring various neural states is indeed possible, and the interest about measuring and monitoring brain activity has been in the rise in recent years. The increase in popularity of wearable technology in the past few years, along with the development and improvement of brain scanning technology, will definitely improve the performance, precision, and usability of brain scanning devices.

Emotiv EPOC+ obviously has some comfortability problems, but other than that, it is a good candidate to be used in future research. Therefore, from here onward we continue with detection and classification of mental workload, stress, fatigue using Emotiv EPOC+, as well as measure what are the effects on productivity as a result. Afterwards, we need to assemble the parts together, resulting in the actual implementation of Emendo.

Lastly, the implicit aim of this paper is to present another dimension of doing research in software engineering that can allow us to improve how we develop code, as well as to understand better the whole process of software development and the individual parts of it.

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