

Suggestion of the Eye-tracking system based Fitness-for-duty Evaluation Methodology in Nuclear Power Plants

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1. Introduction

UAE has the culture imposing people to work much without breaks. Chronic fatigue and stress caused by long working hours are taking a heavy toll on the UAE's work force. A survey by YouGov Siraj found that 59 percent of UAE residents were stressed out, 65 percent because of increased workloads. Another survey targeting worker at 73 companies in Arab found that 'work-life balance' is collapsed by stress and fatigue due to such as lack of sleep. As Korea exported nuclear power plants to UAE in 2009, Korean operators will be dispatched to UAE for work. Because of changed states, there are some possibilities that they feel homesick.

These problems can lead to human errors in operating nuclear power plants in UAE. In nuclear industry, there were total 68 accidents and incidents from 2010 in Republic of Korea. The main contributors of these events can be classified into human error, mechanical failure, electrical failure, instrumentation failure, and external factor. Among these events, about 20% of events was caused by human errors of operators and other personnel [1]. Moreover, human factors were also involved in the occurrence of Chernobyl, Three-mile Island and Fukushima Daiichi nuclear accidents [2-4]. The reduction of the accidents caused by human error is essential to improve the safe operation of safety-critical systems such as aviation and nuclear systems.

In this research, a novel system to inspect work preparedness condition will be developed to reduce human errors in the safety-critical industries. It is expected that the proposed system can be applied to inspect various physical and emotional conditions such as tiredness and to enhance public safety and productivity while operating UAE nuclear power plants.

Emotion monitoring techniques using body signals were applied to enhance the safety in various fields and these techniques have been already commercialized (BMW, Toyota, GM, Samsung, etc.) [5]. The techniques have been applied in the development of IoT(internet of things) technique and wearable device.

These techniques are expected to contribute for reducing the accidents caused by human errors in nuclear and aviation industry significantly [6] and they are also predicted to contribute to reducing of elderly driver accident.

Previous studies were focused on improving situation awareness of operators by using operator support

systems, digitalized procedure systems, etc. However, this research considers fitness-for-duty of the operators. If there are systems or methodologies to detect operators who feel very tired due to fatigue or stress before they work in main control room, human errors are expected to be reduced. Therefore, development of methodology for bio-signal based fitness-for-duty evaluation system of worker is necessary for improving NPPs' safety by reducing human errors.

2. Selection of a method for measuring fatigue & stress: Eye tracking system

Lots of bio signal measures for measuring fatigue are exist such as EEG, ECG, GSR, eye tracking measurement, etc. Four criteria were selected considering tasks of NPPs' operators.

- 1) Non-invasive measurement method
- 2) Unaffecting operators' tasks
- 3) Simple and easy measurement method
- 4) Reasonable accuracy

2.1 Electroencephalogram (EEG)

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain [7]. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time [7] as recorded from multiple electrodes placed on the scalp. Diagnostic applications generally focus on the spectral content of EEG, that is, the type of neural oscillations (popularly called "brain waves") that can be observed in EEG signals.

Classification of EEG [8]

- δ -wave: 0.2~3.99 Hz (Sleeping)
- θ -wave: 4~7.99 Hz (resting or before sleeping)
- α -wave: 8~12.99 Hz (being comfortable)
- β -wave: 13~30 Hz (conscious state)
- γ -wave: 30~50 Hz (being impatient or performing high cognitive activity)

2.2 Eye tracking

Eye tracking is the process of measuring either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement. Eye trackers are used in research on the visual system, in psychology, in psycholinguistics, marketing, as an input device for human-computer interaction, and in product design. There are a number of methods for measuring eye movement. The most popular variant uses video images from which the eye position is extracted. Other methods use search coils or are based on the electrooculogram.

Tracker types:

Eye trackers measure rotations of the eye in one of several ways, but principally they fall into three categories: (i) measurement of the movement of an object (normally, a special contact lens) attached to the eye, (ii) optical tracking without direct contact to the eye, and (iii) measurement of electric potentials using electrodes placed around the eyes.

(i) Eye-attached tracking

The first type uses an attachment to the eye, such as a special contact lens with an embedded mirror or magnetic field sensor, and the movement of the attachment is measured with the assumption that it does not slip significantly as the eye rotates. Measurements with tight fitting contact lenses have provided extremely sensitive recordings of eye movement, and magnetic search coils are the method of choice for researchers studying the dynamics and underlying physiology of eye movement. It allows the measurement of eye movement in horizontal, vertical and torsion directions [9].

(ii) Optical tracking

The second broad category uses some non-contact, optical method for measuring eye motion. Light, typically infrared, is reflected from the eye and sensed by a video camera or some other specially designed optical sensor. The information is then analyzed to extract eye rotation from changes in reflections. Video-based eye trackers typically use the corneal reflection (the first Purkinje image) and the center of the pupil as features to track over time. A more sensitive type of eye tracker, the dual-Purkinje eye tracker, [10] uses reflections from the front of the cornea (first Purkinje image) and the back of the lens (fourth Purkinje image) as features to track. A still more sensitive method of tracking is to image features from inside the eye, such as the retinal blood vessels, and follow these features as the eye rotates. Optical methods, particularly those based on video recording, are widely used for gaze tracking and are favored for being non-invasive and inexpensive.

(iii) Electric potential measurement

The third category uses electric potentials measured with electrodes placed around the eyes. The eyes are the

origin of a steady electric potential field, which can also be detected in total darkness and if the eyes are closed. It can be modelled to be generated by a dipole with its positive pole at the cornea and its negative pole at the retina. The electric signal that can be derived using two pairs of contact electrodes placed on the skin around one eye is called Electrooculogram (EOG). If the eyes move from the centre position towards the periphery, the retina approaches one electrode while the cornea approaches the opposing one. This change in the orientation of the dipole and consequently the electric potential field results in a change in the measured EOG signal. Inversely, by analyzing these changes in eye movement can be tracked. Due to the discretization given by the common electrode setup two separate movement components – a horizontal and a vertical – can be identified. A third EOG component is the radial EOG channel, [11] which is the average of the EOG channels referenced to some posterior scalp electrode. This radial EOG channel is sensitive to the saccadic spike potentials stemming from the extra-ocular muscles at the onset of saccades, and allows reliable detection of even miniature saccades [12].

2.3 Galvanic Skin Reflex (GSR)

The traditional theory of GSR holds that skin resistance varies with the state of sweat glands in the skin. Sweating is controlled by the sympathetic nervous system, [13] and skin conductance is an indication of psychological or physiological arousal. If the sympathetic branch of the autonomic nervous system is highly aroused, then sweat gland activity also increases, which in turn increases skin conductance. In this way, skin conductance can be a measure of emotional and sympathetic responses [14]. More recent research and additional phenomena (resistance, potential, impedance, and admittance, sometimes responsive and sometimes apparently spontaneous) suggest this is not a complete answer, and research continues into the source and significance of GSR.

2.4 Skin Temperature

Evaluating stress index can be measured by measuring skin temperature. Measuring nose skin temperature is accurate because peripheral blood vessel is closely located under nose skin.

The process is as follow:

- 1) Getting stress
- 2) Sympathetic nerves stimulus
- 3) Peripheral blood vessel constricts
- 4) Blood flow decrease
- 5) Nose temperature goes down
- 6) Nose temperature is measured

Table 1. Evaluating each measurement

Measurement	Types	Non-invasive	Unaffecting operators' tasks	Simple and easy method	Reasonable accuracy
EEG	Bio electric signals	o	x	x	o
Eye tracking	Bio mechanical signals	o	o	o	o
GSR	Bio impedance signals	o	x	△	o
Skin temperature	Bio optical signals	o	o	o	x

Various bio-signal related documents were scrutinized. Three categories of fatigue measurements are introduced by US-NRC.

- 1) Physiological measurements (EEG, Gene analysis, etc.)
- 2) Physical/behavioral measurements (Wrist actigraph, Eye tracker, etc.)
- 3) Cognitive measurements (Specific measurements do not exist)

NRC said that eye tracker is the most common method of measuring fatigue [15]. According to the table; eye tracking is the best measurement to measuring bio-signal of NPPs' operators. It also satisfies the four criteria.

3. Experiment Design

An experiment was conducted to suggest the methodology to evaluate the fitness-for-duty of nuclear operators.

3.1 Test subject & Equipment

About 30 students majoring in nuclear engineering participated in the experiments. Compact Nuclear Simulator (CNS) and Tobii Pro X3-120 eye tracker equipment(Screen-based eye tracker and it has a sampling rate of 120Hz) are used in the experiments. We invited subjects who felt various fatigue.

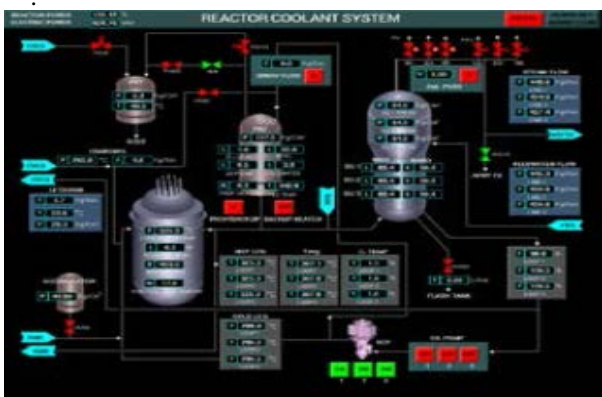


Figure 1. Screen of Compact Nuclear Simulator

3.2 Accident Scenario

We give the random accident scenario to the subjects. The subjects conduct monitoring the MMI systems, and they should diagnose what the accident is.

3.3 Measured data

We measured "Fatigue Subjective Symptoms Test" and various data related to eye tracking such as "Time to first fixation", "First fixation duration", "Fixation count", "Visit count", etc.



Figure 2. Eye tracking data analysis

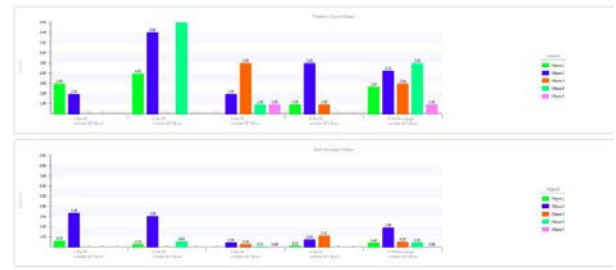


Figure 3. Statics interpretation of eye tracking data analysis (ex, fixation count, visit duration, etc)

4. Summary & Conclusion

We scrutinized methodologies of measuring human performance and correlation analysis of bio-signals and human performance. US-NRC has been focusing on drug and alcohol testing and fatigue management. Most factors which affecting human performance are caused by fatigue in terms of fitness for duty. In addition, drugs intake of operator is considered pretty rare in safety critical system operations. In this study, we dealt with measurement of fatigue (physiological indicators and their measurement, physical/behavioral indicators and their measurement, and cognitive and affective indicators and their measurement) only. In addition, fatigue-related technologies were surveyed. US-NRC said eye tracker is the most common method of measuring fatigue in terms of fitness for duty.

We will statistically analyze the eye tracking data of the subjects with varying degrees of fatigue to find a suitable state for nuclear power plant operations. We will also analyze the eye tracking data of highly stressed or stressed subjects to find out what is not suitable for the works of the plant and suggest ways to present it in advance.

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