Human state estimation system implemented in an Office Deployable Getaway based on multiple bio information

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Abstract –

This article is proposing a human state estimation system on the basis of multiple bio information implemented into a movable cover chair called "Office Deployable Getaway". The proposed system consists of 2 sub-systems; the first sub-system analyzes fatigue based on eye movement including blinking rate and eye closure time while the second sub-system analyzes breath frequency. These indicators are detected by applying image processing to IR images, using the Microsoft Kinect sensor. Hardware tests were conducted to determine the proper Microsoft Kinect (Kinect V1 or Kinect V2) and its position inside the chair to efficiently detect eye movement and respiration. The experimental results showed that these bio information could be measured appropriately under the condition that the Kinect V2 was set at the eye level opposite from the user. Based on the result, the implementation of the proposed system into the chair was carried out, installing the Kinect and a personal computer at appropriate positions. Finally, this system was tested in a real environment with test person sitting inside the chair; after the fatigue is analyzed over eye movement, breath frequency is analyzed. The results of these analyzations are indicated in the computer screen. This performance test showed that this system could be feasible for the realistic use. For future development, the authors will focus on audio system that triggers proper music based on estimated human state, which will be implemented into this chair.

Keywords –

Human-Machine-Interaction, Breath Detection, Fatigue Analyzation, Human Mood, Eye Recognition, Ambient Assisted Living

1 Introduction

It is considered that fatigue contributes to 20% of reported accidents across all sectors [1]. As the construction industry involves hazardous operations of machine tools, accumulation of fatigue might increase the risk of fatal accidents [2, 3]. Thus, getting enough rest is vital to staff safety especially in construction site. For this purpose, LIQUIFER Systems Group (in Vienna) has developed "Deployable Getaway for the Office" [4], which is a chair with a mobile, ergonomic, and transformable 'cocoon-like' structure that office staffs may utilize during the workday. It is expected that this chair could also provide construction staffs with private rejuvenation space. However, they sometimes fail to take enough rest due to increase in construction orders. Accordingly, this article is proposing a human state estimation system on the basis of multiple bio information implemented into "Deployable Getaway for the Office". The captured bio information will be used to trigger music, which will influence the mood of the person to improve his safety.

There has been a growing interest in human state estimation systems. Earlier studies proposed fatigue detection system for drivers using eye movement (eye closure time and blinking rate) [5 – 7]. Additionally, previous studies suggested that breath frequency or breathing capacity extracted from breath wave could be used as index to detect stress level [8, 9]. Therefore, the authors proposed the human state estimation system that consists of two sub-systems; the first sub-system analyzes fatigue based on eye movement including eye closure time and blinking rate, while the second sub-system analyzes breath frequency.

Regarding the method to capture bio information, methods using wearable sensors have been developed [10 – 12]. These methods provide high accuracy although their usage might be troublesome as the users must always remember to wear them. In order to solve this problem, image processing methods have been drawing intense research interest because of their contactless sensing [13]. However, the image processing is problematic in that it is easily affected by lighting condition. Given the fact that it is dark inside the chair, the image processing is applied to IR images instead of RGB images, obtained by the Microsoft Kinect sensor.

For the implementation, hardware tests were conducted where the proper Microsoft Kinect sensor (Kinect V1 or Kinect V2) and its proper position inside the chair were examined. In accordance with the results, the proposed system was implemented into Deployable Getaway Chair installing Kinect V2 and mini PC. Finally, the performance of the proposed system was examined with a test person sitting inside the chair to show its feasibility.

2 Proposed System

In order to run human state estimation system, the authors conducted hardware tests, where the proper device and its position inside chair were examined.

2.1 Hardware Tests

A device which could obtain images in low light condition is required for the human state estimation system. Accordingly, the author considered introduction of Microsoft sensor Kinect (Kinect V1 or Kinect V2) with IR image sensor that could function under the dark condition. In addition, they are easy in installation. The Kinect V2 could provide adequate performance for the implementation, though its cost is slightly higher compared to Kinect V1. Thus, the authors examined whether Kinect V1 could function through some tests. Kinect V1 mounts image sensor, distance sensor and microphone. Table 1 shows specifications of Kinect V1.

Experiments were conducted where a picture of subject was taken with Kinect V1. The obtained image included heavy noise which could cause difficulty in capturing bio-information. Accordingly, 2 kinds of image processing methods were applied to reduce the noise; "averaging method" and "erosion and dilation method". However, it was shown that these image processing methods were not sufficient to reduce the noise of image obtained by Kinect V1. The result showed that Kinect V2 should be introduced as a sensor for this proposed system.

For the installation of the device, experiments were carried out to find the best place to mount Kinect inside the chair. The authors attached importance to measure eye and chest parts with the same camera settings. In order to investigate the best angle and distance conditions for capturing bio information, experiments were conducted with several positions of the Kinect V2. Experimental results suggested that both eye movement and breath could be detected when Kinect V2 was set eye level within 0.8 m from the subject. According to the results, PC and Kinect V2 were installed into Deployable Getaway Chair as is shown in Figure 1.

Table 1. Specification of Kinect V1

RGB image resolution	640 × 480 pixel
Depth image resolution	640 × 480 pixel
Measurable distance	0.8 ～ 10 m
Infrared viewing angle	Horizontal: 57° Vertical: 43°
Frame rate	30 fps

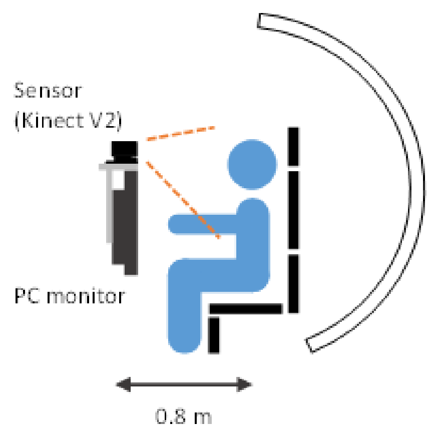

Figure 1. Position of Kinect for implementation (Created based upon data from [14])

2.2 Installation of Office Deployable Getaway

Depending on the obtained results, the devices such as PC and Kinect V2 were installed into the chair.

2.2.1 Deployable Getaway Chair

LIQUIFER SYSTEMS GROUP (in Vienna) has been taking on the "Deployable getaway" project [15], which promotes design of the space with space-efficient storage and a flexible set-up for more privacy; "Deployable Getaway for the international space station" and "Deployable getaway for the office".

"Deployable Getaway for the international space station" refers to the relaxation space for astronauts on long space trips. The design for relaxation space for astronauts who travel under space constraints might be applied to these for handicapped people on wheel chairs or elderly people who move in relatively small area inside their home.

For the implementation, the authors introduced

"Deployable getaway for the office". As illustrated in Figure 2 and Figure 3, this chair has transformable 'cocoon-like' structure. As can be seen from Figure 4, closing the cover provides dark space where employees may utilize in busy office environments for the purpose of rejuvenation.

Figure 2. Deployable Getaway for the Office; cover is open (Reprinted from [14])

Figure 3. Deployable Getaway for the Office; cover is close (Reprinted from [14])

Figure 4. "Cocoon-like" structure (Reprinted from [14])

2.2.2 Installation

Based on the results obtained by hardware tests, the devices such as Kinect V2 and mini PC needed for the implementation were installed into the appropriate position inside Deployable Getaway Chair. The specifications of the devices are mentioned in Table 2 and Table 3. Table 2 shows specifications of mini PC. Kinect V2 mounts image sensor, distance sensor and microphone. The specifications of Kinect V2 are listed in Table 3. Figure 5 shows Deployable Getaway for the Office equipped with Kinect V2 and mini PC.

Table 2. Specification of mini PC

Windows edition	Windows 8.1Enterprise
Processor	Intel® Core(TM) i7-4770T CPU@2.50GHz
Installed memory RAM	8.00 GB
System type	64-bit Operating System, x64-based processor

Table 3. Specification of Kinect V2

RGB image resolution	1920 × 1080 pixel
Depth image resolution	512 × 424 pixel
Measurable distance	0.5 ～ 4.5 m
Infrared viewing angle	Horizontal: 70° Vertical: 60°
Frame rate	30 fps

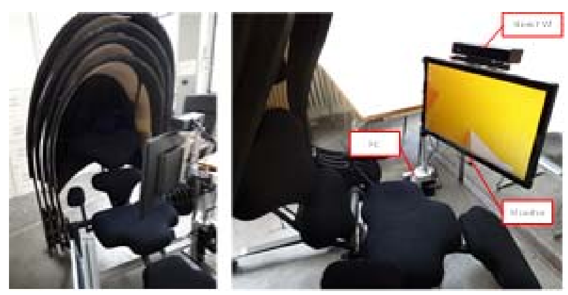

Figure 5. Chair with Kinect and mini PC (Reprinted from [14])

3 Software Architecture

Human state estimation system consists of 2 sub-systems; fatigue detection sub-system and breath detection sub-system. These sub-systems are as follows.

3.1 Fatigue detection sub-system

An overview of fatigue detection sub-system is shown in Figure 6. First, Kinect takes images of subject and stores the eye area. If the eye area is stored, image preservation starts. After enough images are stored, the eye is extracted from the images according to the stored eye area. Then, the extracted eye is classified as open eye or close eye to measure eye closure time and blinking rate. Based on the obtained data, fatigue is detected and the results is shown on the PC display.

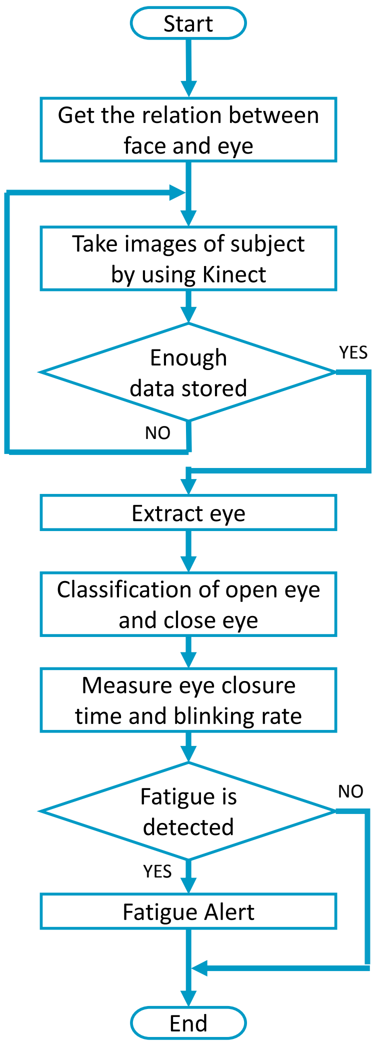

Figure 6. Flowchart of fatigue detection system

3.1.1 Eye segmentation

Eye segmentation was done by object detection based on Haar-like features using Open CV library [16 – 18]. Loaded xml file as object detector (face detector or eye detector) detects the desired object included in image. Accordingly, frontal face detector detects the face. Then, eye detector detects the eye from extracted face area. However, this eye detection algorithm tends to fail to detect eye, so that the relationship between eye and face was introduced for robust eye tracking algorithm; when the eye is detected for the first time, the relationship of face area and eye area are stored as r_x and r_y given in the equations (1) and (2) [14]. The variables used in these equations are illustrated in Figure 7. Numbers included in variables refer to frame number.

$$r_x = \frac{eye.x(1)}{face.width(1)} \tag{1}$$

$$r_y = \frac{eye.y(1)}{face.height(1)} \tag{2}$$

Assuming that subjects don't move forward or backward, *eye.height* and *eye.width* are defined based on preparatory experiments.

Drawing on the relationship, eye area is estimated when face area is detected as shown in equations (3) and (4) [14]. Here *n* refers to frame number.

$$eye.x(n) = r_x \cdot face.width(n) \tag{3}$$

$$eye.y(n) = r_y \cdot face.height(n) \tag{4}$$

This method could achieve accurate and stable eye area estimation because face detection could achieve higher accuracy and better robustness compared to eye detection based on Haar algorithm.

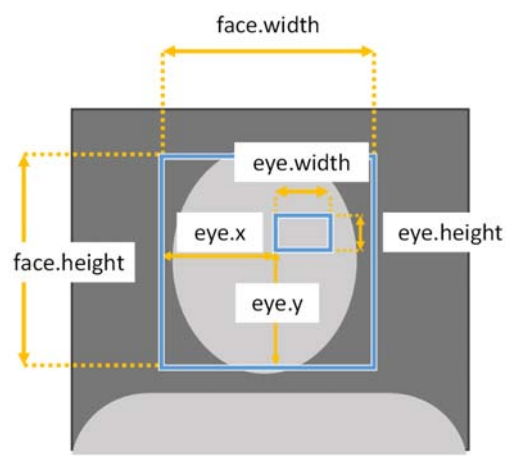

Figure 7. Eye segmentation (Created based upon data from [14])

3.1.2 Eye classification

In order to classify open eye and close eye, vertical projection curve was focused. Figure 8 shows the vertical projection curve of open eye image and close eye image. From this figure, it can be observed that the vertical projection curve of close eye image is flat compared to that of open eye image. Therefore, this difference in vertical projection could serve to classify open eye and close eye.

The valuable for the classification was calculated as *Change Factor* (represented as *CF*). *CF(n)* that refers to *CF* of nth frame was calculated as follows. First, vertical projection curve of 1st frame $\boldsymbol{V}(1)$ and that of nth frame $\boldsymbol{V}(n)$ were normalized as shown in equations (5) and (6) [14]. Here $\boldsymbol{f}_{1dim}(1)$ represents normalized $\boldsymbol{V}(1)$ while $\boldsymbol{f}_{1dim}(n)$ represents normalized $\boldsymbol{V}(n)$.

$$\boldsymbol{f}_{1dim}(1) = \frac{\boldsymbol{V}(1)}{max(\boldsymbol{V}(1))} \cdot 100 \tag{5}$$

$$\boldsymbol{f}_{1dim}(n) = \frac{\boldsymbol{V}(n)}{max(\boldsymbol{V}(n))} \cdot 100 \tag{6}$$

$CF(n)$ is calculated as the max value of difference between $\boldsymbol{f}_{1dim}(1)$ and $\boldsymbol{f}_{1dim}(n)$ given in equation (7).

$$CF(n) = \max(\boldsymbol{f}_{1\text{dim}}(1) - \boldsymbol{f}_{1\text{dim}}(n)) \tag{7}$$

By applying appropriate threshold to classify *CF* of open eye and that of close eye, eye classification is conducted. For more accurate classification, adjustment of threshold is required depending on the experimental situations.

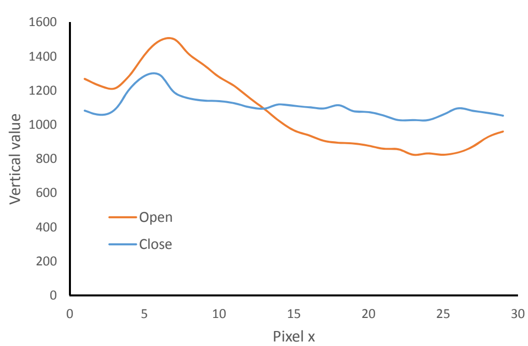

Figure 8. Vertical projection curve of open eye and close eye (Created based upon data from [14])

3.1.3 Fatigue detection

As mentioned above, eye was classified as open eye or close eye to calculate blinking rate and eye closure time. Previous research has suggested that blinking rate and eye closure time could serve as a baseline to detect fatigue [19]. Accordingly, the authors referred to this research to construct fatigue detection system using obtained eye information.

3.2 Breath detection sub-system

An outline of breath detection sub-system is illustrated in Figure 9. First, images of a subject is stored. After enough data are stored, chest part is extracted from the obtained image so that get rid of the effects caused by hand movements or head movements. Image processing was applied to extracted image to detect slight chest movement and obtain respiration wave. Then, Fourier transformation was applied to the detected respiration wave to calculate respiration rate.

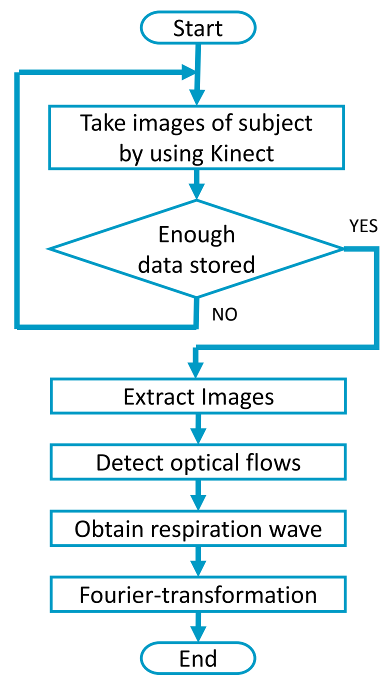

Figure 9. Flowchart of breath detection system

3.2.1 Breath detection using optical flow

As an image processing method to measure the slight chest movement, detection of optical flow method was introduced. Optical flow is vector that represents velocity field calculated from successive 2 frames. The detail of this method is shown below. First, optical flows are detected from successive 2 frames. One of the detected optical flows $\boldsymbol{v}(i)$ is shown in Figure 10. In order to make a distinction between movement of inhalation and that of exhalation, the y direction of optical flow $\boldsymbol{v}(i)$ is focused, represented as $v_y(i)$.

By averaging optical flows detected within extracted area every frame, averaged optical flow $v_{ave}(i)$ is calculated shown in equation (8). Here n represents total optical flows detected per 1 frame.

$$v_{ave} = \frac{1}{n}\sum v_y(i) \tag{8}$$

The variable v'_{ave} is calculated given in equation (9) to obtain respiration wave.

$$v'_{ave} = \frac{v_{ave}}{dt} \tag{9}$$

For reduction of heavy noise included the obtained respiration wave, approximation based on least squares method is necessary. Then, Hanning Window and Fourier transformation have been applied to the obtained respiration wave to calculate respiration rate.

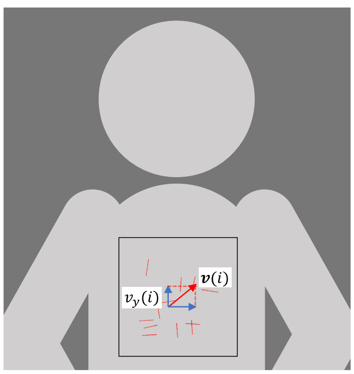

Figure 10. Detection of optical flow (Created based upon data from [20])

4 Measurement results and mood influence

In this chapter, verification experiments on human state estimation system have been carried out. Additionally, an audio system for mood control is scheduled for future development.

4.1 Verification experiments

After the proposed system was improved, further experiments have been conducted to test the performance of fatigue detection sub-system and breath detection sub-system. Experiments on fatigue detection system tested the detection of eye movement where the method to measure eye movement (see Section 3.1) was applied to data-set consists of 2000 images that equals to about 1 minute data. By comparing the obtained result and image data, accuracy of eye detection and eye classification were evaluated. As a result, the correct rate for eye detection could achieve 97.5%. Figure 11 shows the measurement result. From this figure, it can be seen that the proposed system has high accuracy of classification of open eye and close eye, which could lead to calculate eye closure time and blinking rate accurately.

Moreover, experiment on breath detection sub-system has been conducted; first, images of subject breathing for 1 minute were stored while the breath sound was recorded. Then, the breath detection sub-system was applied to the stored images. By comparing the obtained results (sound and image data), the accuracy of the breath detection sub-system was evaluated. Figure 12 illustrates an example of measurement result; the upper graph represents the recorded breath sound wave while the lower graph represents respiration wave obtained by the proposed system. From this figure, it was found that the proposed system could detect respiration wave properly.

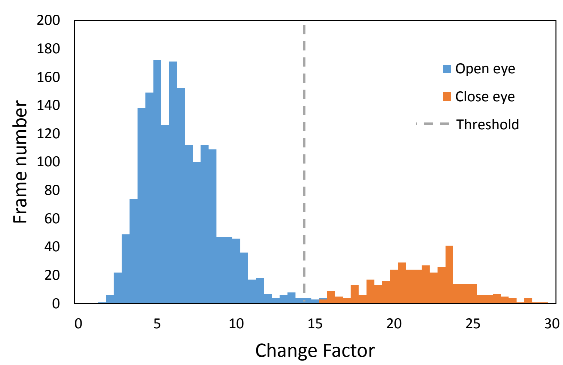

Figure 11. Measurement result of eye movement

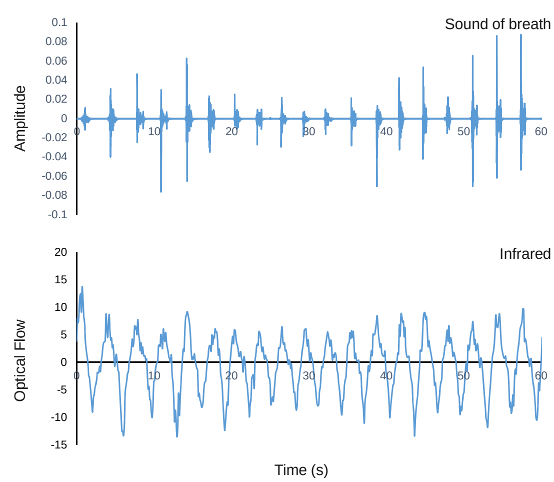

Figure 12. Measurement result of breath

4.2 Performance test on Deployable Getaway

Human state estimation system was implemented into Deployable Getaway Chair. The performance of the proposed system has been demonstrated with a test person sitting inside the chair; after the fatigue is analyzed over eye movement, breath frequency is analyzed. The results of these analyzations are indicated in the computer screen. Thus, this test suggested the feasibility of the proposed system.

4.3 Audio system for mood control

As a next step, it is required to construct an audio sub-system to trigger music for mood control based on the multiple bio-information captured by the human state estimation system. As this system is intended to let tired people get relaxed, fatigue detection is used as an input while breath detection is used for the audio system for mood control.

The authors focus on meditation as the method for mood control during rejuvenation. A previous research has suggested that *Tanden* respiration during Zen meditation could reduce negative mood and let people get relaxed, which might improve staff safety [21]. Accordingly, the authors take on the audio system that induces the proper respiration for meditation. An earlier study suggested that repeated phrase could be effective to control respiration [22]. Thus, sea wave sound is introduced for this audio system.

The detail of the audio system is described as follows. As soon as the fatigue is detected, the audio system is triggered, which influences the mood of the user at appropriate timing. It induces the desired respiration for the meditation starting from the breath rate obtained by the proposed system. This audio system will be implemented into the Deployable Getaway Chair with private space for meditation to increase staff safety.

5 Discussion

In this paper, the authors proposed a human state estimation system on the basis of multiple bio information implemented into "Office Deployable Getaway" which refers to a chair used as a work-station in busy office environments. The proposed system consists of 2 sub-systems; the first sub-system analyzes eye movement including blinking rate and eye closure time to detect fatigue while the second sub-system analyzes breath frequency. These indicators were detected by applying image processing to IR images obtained by Microsoft Kinect sensor. By so doing, bio information of the user could be captured non-contactly even under the dark environment.

Hardware tests were conducted to determine the proper Microsoft Kinect sensor (Kinect V1 or Kinect V2) and its position inside the chair to efficiently detect multiple bio-information including eye movement and respiration. The test results suggested that these bio information could be captured efficiently under the condition that the Kinect sensor V2 was installed at the eye level opposite from the user. Based on the result, the implementation of the proposed system into the chair was conducted, installing the Kinect and a personal computer at appropriate positions.

Performance tests on fatigue detection sub-system and breath detection sub-system were conducted to ascertain that both eye movement and breath could be captured properly. Accordingly, the proposed system was tested with test persons sitting inside the Deployable Getaway Chair; after the fatigue is analyzed over eye movement, breath frequency is analyzed. The results of these analyzations are indicated in the computer screen. Therefore, it was shown that this system could be feasible for the realistic use.

It remains a challenge for future research to improve the human state estimation system. Through this research, it was shown that there were 3 points of improvement. The first improvement point is long processing time; as the process to store images and the process to analyze images were conducted individually, the overall processing time tends to take long. In order to reduce the processing time, it is necessary to conduct these process at the same time by introducing multi thread program.

The second improvement point is influence caused by movements; it was observed that bio information could not be captured when the subject moved during measurement session. Hence, further work is on the way to reduce the influence caused by body movements.

The third improvement point is noise included in the obtained respiration wave; it was observed that some noises were included in the obtained respiration wave due to the distance between a subject and Kinect V2 or influence of experimental situations such as sun light. As a countermeasure, the authors are taking on the noise reduction system based on function approximation, the performance test of which provides promising results. It is expected that the noise reduction system will realize more robust respiration detection.

For future development, the authors will focus on audio system that triggers proper music based on estimated human state, which will be implemented into this Deployable Getaway Chair. It is expected that combination of Deployable Getaway Chair as an architectural environment and the system to control the environment based on the user's bio-information might contribute to safer construction work environment.

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