Estimation of Tension and Concentration Scenes during Crane Operation Using Physiological Indices for Skill Improvement Support

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Abstract. operators' skills have been evaluated visually by a teacher or an instructor of operators, but it is not possible to know the psychological change of the operator. Authors investigate the method which uses the physiological indices to estimate tension and concentration of the crane operators in different skill levels. Electromyogram (EMG) of the masseter muscle and R-R Interval (RRI) which calculates of heart rate variability (SDNN / RMSSD) are selected. The data were measured in each of the two operation tests of eight operators with different skill levels. As a result, the physiological indices show great reaction to tension and concentration, and the estimation showed that there are characteristics in tension and concentration scenes depending on the skill levels.

Keywords: Tension, Concentration, Masseter EMG, Heart Rate Variability, R-R Interval (RRI), SDNN, RMSSD, Skill Improvement Support

1 Introduction

Growing the construction of many high-rise buildings all over the world, shortage of construction workers is a problem. In particular, crane operators have several difficult tasks which require vast experience and skills. Therefore, the operators need to improve the operation skills from day to day. There is a big difference in technique between an expert and a beginner, and so it is important to improve operator skill efficiently in a short period.

Until now, operator skill have been evaluated visually by a teacher or an instructor of operators. However, it is impossible to know the psychological change of the operator from appearance. If it is possible to estimate and analyze the operators' psychological change in physiological indices of operators, useful information for supporting improvement of operators' skills can be obtained. In addition, it is expected that instructors teach operators to improve skill efficiently using the obtained information.

The interview for operators gained the knowledge that tension and concentration scenes are important because the crane operator should control the shaking load

which is suspended from the wire. Therefore, we estimate tension and concentration among psychological changes in this study.

In tension and concentration scenes, it is known that various physiological reactions of the human body occur, and these relations have been studied [1,2,3,4,5]. According to research of Hayakawa et al., somatic nervous system reacts well on the tension scene, and autonomic nervous system reacts well on concentration scene [6].

There are many studies of estimating tension and concentration scenes during driving [7,8,9], but no research has been done during crane operation. One study examined tension during crane cooperative work using heart rate, blood pressure and respiration in visual reality space [10]. They point out that the operator cannot feel sense of reality as much as they use a real machine. In addition, it is important to clarify and analyze differences depending on skills for efficient skill improvement, but the relationship between skill level and tension and concentration scenes has not yet been analyzed.

Therefore, we measure physiological indices of the somatic nervous system and the autonomic nervous system of the crane operator under operation. The purpose of this study is estimation of tension and concentration during crane operation. Also, we measure indices in experiments on operators with different skills and find characteristics in tension and concentration scenes depending on the skill levels.

2 Method

The method of this study is divided into 4 steps. First, the physiological indices are measured during crane operation. Second, tension and concentration are estimated from measured indices. Then, we extract tension and concentration scenes from interview of operators and recorded videos of experiment. These information is used for a subjective index of operators. Next, we extract tension and concentration scenes by comparing scenes obtained by subjective indices to scenes of physiological indices. Lastly, characteristics of tension and concentration scenes are clarified for each crane operators who have different skills.

2.1 Physiological indices

In the tension and concentration scenes, various physiologic indices change. However, it is necessary to consider four points in order to measure physiologic indices of the operators safely during crane operation.

- Measured indices should be robust over noise due to the body motion in the surrounding environment and work (noise tolerance).
- Measurement should be continuous during operation (continuity).
- Measurement should be less burden and impact for subjects' operation (burden).
- Measured indices should represent tension or concentration well (relevance).

In consideration of these requirements, masseter muscle activity is used from somatic nervous system reactions and heart rate variability from autonomic nervous

system reactions, which can be more accurately measured without a heavy burden on operators.

An index of tension (Masseter EMG) It is known that the root mean square (RMS) of the masseter muscle electromyogram (EMG) increases on the tension scenes by previous studies [4]. This study also uses the same index of tension S_1. Considering the potential frequency band of EMG in previous research [11], high pass filter of 10 Hz is applied to the signal from the EMG sensors. Assuming that this filtered signal at sample point n is e (n), the RMS of EMG $S_1(n)$ can be obtained by equation (1).

$$S_1(n) = \sqrt{\frac{1}{N+1}\sum_{i=0}^{N} e^2\left(n - \frac{N}{2} + i\right)}, \tag{1}$$

$$N = fT, \quad \frac{N}{2} \le n \le n_{\text{end}} - \frac{N}{2}.$$

Here, n_{end} is the last sample point, f is the sampling frequency, and T is the analysis window size. We set $S_1(n)$ to be an index for the tension scene estimation on the masseter muscle activity.

An index of concentration (Heart rate variability) It is known that concentrations can be understood by analyzing heart rate variability by previous studies [12,13], and we use this as an index of concentration S_2. The fluctuation of human heartbeat interval is called heart rate variability. R-R Interval (RRI) is obtained by the R wave detected from the electrocardiogram, and it is set as the heart beat interval. The time to record RRI is the midpoint between successive R waves.

In this study, we use the ratio of Standard Deviation of the Normal to Normal Interval (SDNN) to RMS of the Successive Differences of RRI (RMSSD), which are superior as a short time domain analysis method [14,15]. SDNN is an index representing the activity state of both the sympathetic nervous system and the parasympathetic nervous system [16]. RMSSD is an index representing the activity state of the parasympathetic nervous system [17,18]. Therefore, an index S_2 is defined as ratio of SDNN to RMSSD, representing the activity state of the sympathetic nervous system, namely the source of concentration.

Assuming that RRI, SDNN, RMSSD and S_2 at sample point n are $I(n)$, $R_{\text{SD}}(n)$, $R_{\text{RM}}(n)$ and $S_2(n)$, average value of RRI in analysis section is $\bar{I}$, then SDNN, RMSSD and the ratio of them $S_2(n)$ can be obtained by equations (2), (3) and (4).

$$R_{\text{SD}}(n) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(I\left(n - \frac{N}{2} + i\right) - \bar{I}\right)^2}, \tag{2}$$

$$R_{\text{RM}}(n) = \sqrt{\frac{1}{N+1}\sum_{i=2}^{N}\left(I\left(n - \frac{N}{2} + i\right) - I\left(n - \frac{N}{2} + i - 1\right)^2\right)}, \tag{3}$$

$$S_2(n) = R_{\text{SD}}(n)/R_{\text{RM}}(n), \tag{4}$$

$$\frac{N}{2} \leq n \leq n_{\text{end}} - \frac{N}{2}.$$

Here, n_{end} is the last sample point, and N is the number of analysis samples. We set $S_2(n)$ to be an index for the concentration scene estimation on the heart rate variability.

2.2 Estimation method

Before operation, the physiological indices are measured and we obtain average values $A_{1,2}$ of $S_{1,2}(n)$ at rest. Setting the thresholds to k_1A_1, k_2A_2, respectively, we check and set the values sufficiently exceeding the value occurring on resting situation by gradually increasing k_1, k_2 so that the reaction can be properly detected.

Also, in order to determine the tension and concentration scenes from physiological indices measured from different subjects, the crane operation is divided into 42 scenes. The scene on which indexes S_1 and S_2 exceed the threshold for 25 ms, and 100 ms respectively is determined to be tension or concentration scenes.

3 Measurement experiment during crane operation

Measurement experiment was carried out using a rough terrain crane GR250N-1 at the Tadano Training Center practical test course on August 5 and 6, 2015. In the experiment, operators were told to carry the load along the designed course which is divided into 21 consecutive actions. Fig. 1 shows the course and it requires the operator to move the load between obstacles (pole, bar and net) and to move it back to the start point. The subjects were eight male operators in total between 28 years to 58 years old, but one of them was excluded because his data has too high noise to analyze. They are classified under three different skill groups by how much time they have been operating the crane. Beginners have operated for less than 100 hours, intermediates have operated for less than 1000 hours, and experts have operated for more. Each of the 7 subjects was subjected to 1 resting measurement before operations and 2 test measurements during operations.

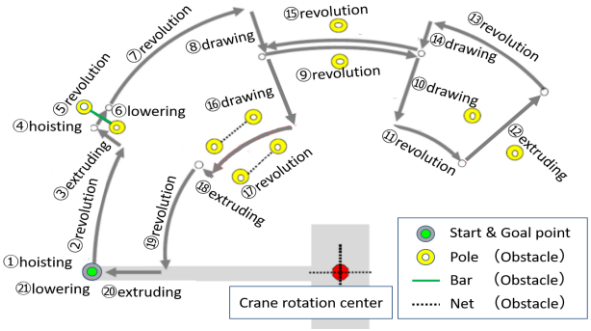

Fig. 1. Tadano Training Center practical test course

After each measurement, we interviewed about in which scenes they felt either tension or they concentrated. Also, camera (Kodak SP360) was used to record video of the operator and the load simultaneously. Based on these, tension and concentration scenes of subjective index and other conditions were recorded. The measurements in this study were conducted with the approval of the Ethics Committee of the University of Tokyo Engineering Department.

4 Result and Consideration

4.1 Estimation of tension and concentration

Changes in index of tension in the first measurement of one of intermediates are shown in Fig. 2 and changes in index of concentration in the first measurement of one of experts are shown in Fig. 3. The vertical axis represents the strength of the index and the horizontal axis does time. A gray vertical line in graphs indicates the moment of start of each action. Multiple of five are solid lines, and the others are broken lines. Also, the tension and concentration scenes of the subjective indices confirmed by recorded video are gray squares either in the top or in the bottom of the graphs, and other conditions are shown in black squares and italic. Each physiological index well reacts in tension and concentration scenes of subjective index. Considering that index S_2 varies more smoothly than S_1, we tried the coefficient k_1 from 5 to 15 in increments of 1, the coefficient k_2 from 1.5 to 2 in increments of 0.05. Thus investigating the coefficient of the threshold, we set k_1 to 10 and k_2 to 1.75 by try and error.

Setting the threshold as described above to extract the tension and concentration scene, the tension and concentration scenes extracted by the physiological index corresponded to ones by the subjective index in unanalyzed data. From this, it is possible to estimate the tension and concentration scenes of crane operators under operation by our method.

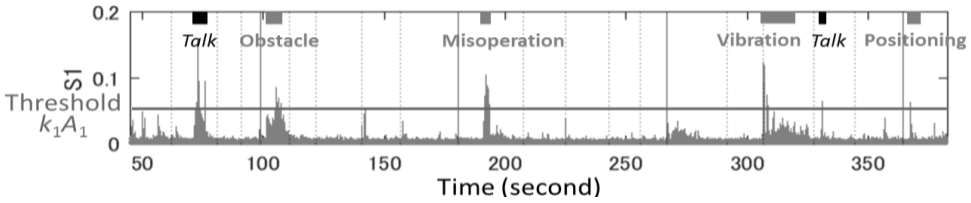

Fig. 2. Changes in index of tension

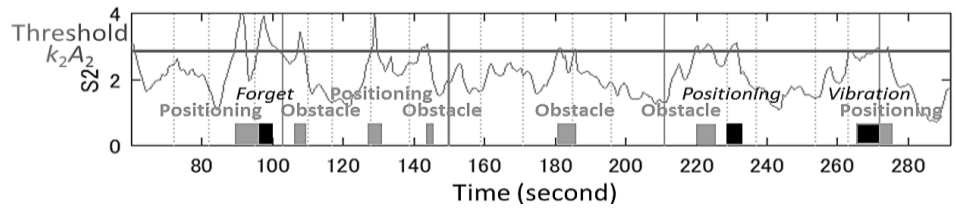

Fig. 3. Changes in index of concentration

4.2 Extraction average of tension and concentration scenes by skill levels

Fig. 4 and Fig. 5 show the extraction results of tension and concentration scenes by skill level. The vertical axis shows the ratio of people who felt tension or who concentrated on the scene, and the horizontal axis shows the 21 actions (Fig. 1 shows). Shaded squares in the graph indicate the scenes which the operators felt difficult during operation, such as obstacle and positioning. Table 1 shows the average of each measurement, divided by skill levels. Beginners felt tension and concentrated in many actions. Also, Table 1 shows that it took a long time for beginners to operate on the whole. This is considered to be due to lack of experience. In addition, intermediates felt tension or concentrated only in the scene where collision or misoperation occurred. This should be because they were careless from self-conceit. Experts concentrated in difficult situations such as scenes of obstacles and positioning. This should be because they could concentrate on important scenes. Actually, beginners had 0.83 collisions with obstacles, intermediate users had 1.00 collisions, but experts did not collide with obstacles, on average for each measurement.

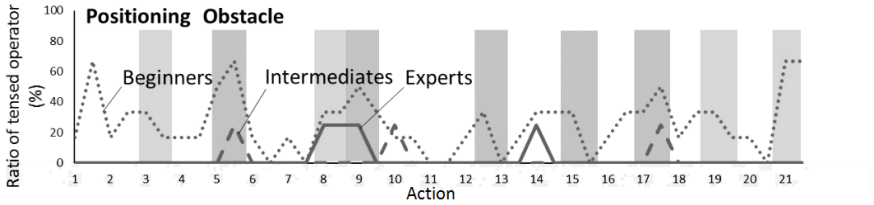

Fig. 4. Extraction average of tension scenes by skill levels

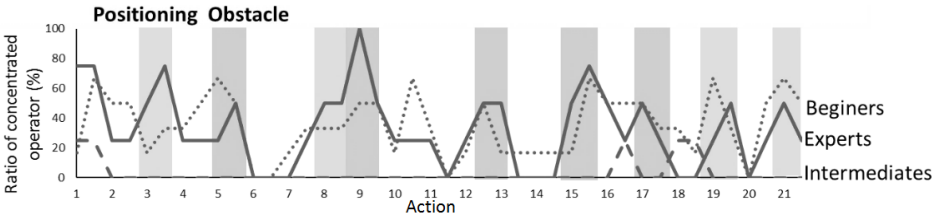

Fig. 5. Extraction average of concentration scenes by skill levels

Table 1. Average of result

Skill level	Tension scene	Concentration scene	Collision	Misoperation	Time
Beginner	26.2 %	35.3 %	0.83	0.83	535 s
Intermediate	1.8 %	3.0 %	1.00	0.75	371 s
Expert	2.4 %	32.7 %	0.00	0.00	289 s

5 Conclusion

We measured the masseter EMG and heart rate variability of the operator during crane operation and proposed a method to estimate tension and concentration scenes based on each physiological index. When comparing the result with the subjective evaluation by the interview and the recorded movie, they were nearly consistent. From this, it is possible to estimate tension and concentration scenes from the physiological indices of the crane operator under operation. In addition, we extracted and analyzed tension and concentration scenes with subjects classified according to skill levels. It became clear that there was a difference depending on experiences in tension and concentration scenes. Beginners often feel tension and concentrate. They take a long time and fail more often than Experts, by reason of lack of training. Intermediates do not concentrate and they fail as often as Beginners. The reason of their failure is lack of care from experience. Experts concentrate on important scenes and can operate stably and smartly. It is possible for beginners to improve their operation skill efficiently by training tension scenes to be experienced, and it is possible for intermediates by operating carefully on the concentration scenes of experts. This work can be used as a skill improvement and accident prevention system by calculating in real time. This is also expected to be used as indices to measure the operability of the operation device. The utility for these way must be confirmed in the future.

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