Assessing Mental Workload of In-Vehicle Information Systems by Using Physiological Metrics

Susumu Enokida[1], Kentaro Kotani[2], Satoshi Suzuki[2], Takafumi Asao[2], Takahiro Ishikawa[3], and Kenji Ishida[3]

[1] Graduate School of Science and Engineering, Kansai University
3-3-35 Yamate-cho, Suita, Osaka 564-8680, Japan
[2] Faculty of Engineering Science, Kansai University
3-3-35 Yamate-cho, Suita, Osaka 564-8680, Japan
[3] Research Laboratories, DENSO CORPORATION
500-1 Komenoki-cho Minamiyama, Nisshin, Aichi 470-0111, Japan
k238046@kansai-u.ac.jp

Abstract. Use of physiological indices including ECGs and EMGs was investigated for estimation of drivers' mental workload induced by using in-vehicle information system (IVIS). The subject performed multiple simultaneous task paradigm consisted of driving using driving simulator, use of car navigation system and stimulus detection task paradigm. The results indicated that muscular loads obtained by EMGs tended to show higher activity in coherent with the level of mental workload and high correlation coefficient between muscular loads. The performance associated with stimulus detection task revealed the potential use of EMG signals as an index for evaluating mental workload.

Keywords: human engineering, bioinstrumentation/driving, physiological measurement, Electromyography.

1 Introduction

Recent advances in in-vehicle information systems (IVIS) have enabled drivers to drive more safely and more conveniently. On the other hand, these systems may decrease drivers' attention to driving or cause driver distraction. Therefore a method for assessing drivers' mental workload when they operate IVIS while driving is needed. The assessment method should be efficient, low cost, and easy to use.

Subjective, behavioral, and physiological indices can assess the mental workload for a certain working condition [1]. Many studies using subjective indices for assessing mental workload have been introduced. NASA-TLX is one of the main evaluation methods [2]. In addition, various behavioral indices have been used for assessing mental workload. In recent years, studies using a multimodal stimulus detection task (MSDT) with the use of the sensory modalities of multiple visual, tactile, and auditory mutually compremental modalities have been developed [3] [4]. This MSDT has been reviewed for standardization as the distraction test for IVIS [5]. As studies using physiological indices for assessing mental workload, event related potentials (ERPs),

S. Yamamoto (Ed.): HIMI/HCII 2013, Part I, LNCS 8016, pp. 584–593, 2013.

electrocardiograms (ECGs), and blood pressure have been extensively investigated [6] [7] [8]. These studies using physiological indices for assessing mental workload reported its potential for detecting influences to a human body by mental strain, however, there have been no clear evidences to establish the level of mental workload by physiological indices, and thus no successful intervention to assess changes of mental workload quantitatively with using physiological indices was available. This study aims to develop an algorithm for the quantitative assessment for mental workload with using physiological indices. In this paper, physiological index reacted by changes of operating IVIS was discussed. In addition, relationship between physiological indices reacted to mental workload and subjective index (NASA-TLX), and a behavioral index (MSDT) were validated. Especially in this paper, identification of physiological indices reacted by mental workload, was empirically conducted. Possibility for assessing mental workload for operating IVIS, using these physiological indices is discussed as well.

2 Experiment

2.1 Participants

Nineteen males participated in the experiment with payment. They were right-handed licensed drivers (average age: 21.7 with a standard deviation of 0.57; average driving experience: 2.79 years with a standard deviation of 1.28). This study was carried out after authorization by the Department of Psychology and Behavioral Sciences Research Ethics Committee of the Graduate School of Human Sciences, Osaka University, with due ethical considerations such as the acquisition of participants' informed consent.

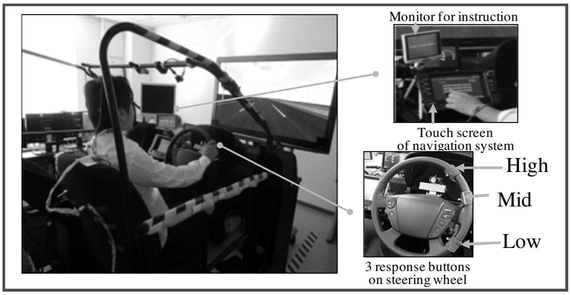

Fig. 1. Experimental Apparatus

2.2 Experimental Tasks and Instructions

The participants performed three tasks at the same time: operating a driving simulator (DS), operating visually-manually a touch panel IVIS, and MSDT. The participants were instructed to perform these tasks in the priority order of DS operation, IVIS operation, and MSDT. The experimental apparatus is shown in Figure 1.

The participants were instructed to operate the DS and follow, without coasting, a leading vehicle running at 80 to 85 km/h in the center lane of a continuously S-curved expressway with three lanes in each direction, while keeping a safe distance from the vehicle in front.

From the start to the end of an experimental session, the participants repeatedly received IVIS operation instructions, operated the IVIS, and suspended the IVIS operations for approximately five seconds. Four IVIS operations were used in the experiment:

(1) Control: The participants didn't operate IVIS. No image transition and no touch control were required.
(2) Map Scroll: The participants scrolled a map image twice in the direction of an arrow instructed in the monitor. Two image transitions and three touch controls were required.
(3) Radio Station Selection: The participants sequentially selected two radio stations instructed in the monitor. Five image transitions and six touch controls were required.
(4) Telephone Number Input: The participants entered a telephone number instructed in the monitor to set a destination. Five image transitions and fourteen touch controls were required.

In the IVIS operation task, the start time was instructed by recorded voice, while the details of the operation were instructed in another monitor located on the rear side of the IVIS screen.

From the start to the end of an experimental session, the participants were repeatedly presented stimuli and instructed to react to each stimulus by pressing a button, and suspend the task. A visual stimulus, a tactile stimulus or an auditory stimulus was presented one at a time in random order. The presentation duration of each stimulus was 300 ms. The participants were required to press one of three buttons mounted on the steering wheel immediately when they perceived one of the above stimuli. The participants were instructed to suspend the task for 2000 to 4000 ms randomly, and to prepare to receive the next stimulus. A reaction within 100 to 2000 ms after the application of a stimulus was regarded as a valid trial. When no reaction was observed within 2000ms, the trial was regarded as a detection error. The experimental session ended at the moment the participants made 60 valid responses for visual stimuli, 50 for tactile stimuli, and 50 for auditory stimuli.

2.3 Experimental Protocol

First we examined (1) DS operation (single task, 3 min), (2) MSDT (single task, 3 min), (3) DS operation plus map scroll on IVIS (dual task, 3 min), (4) DS operation plus radio station selection on IVIS (dual task, 3 min), (5) DS operation plus telephone number input on IVIS (dual task, 3 min) which were not analyzed in this study.

Then we examined the following four conditions to analyze the performance of MSDT in this study: (6) DS operation plus MSDT (dual task, 12 min; CONTROL), (7) DS operation, map scroll on IVIS plus MSDT (triple task, 12 min; MAP), (8) DS operation, radio station selection on IVIS plus MSDT (triple task, 12 min; RADIO), (9) DS operation, telephone number input on IVIS plus MSDT (triple task, 12 min;

TEL). The order of the three levels (7) through (9) was counterbalanced between eighteen of the participants, while the above levels were assigned in a totally randomized manner to the remaining one participant.

During the experiment, the vehicle behavior signals calculated from the DS and participant's biological signals (ECG, EMG, pulse waves, respiration, brain waves, and EOG) were also recorded. After completion of the experiment at each condition, participants rated their subjective workload using the NASA-TLX. However, this paper does not describe the results of the above bioinstrumentation and subjective workload ratings.

The experiment took two days to practice and complete the conditions for each participant.

2.4 Bioinstrumentation

Biological signals measured at the experiment include ECGs, erectromyograms (EMGs), pulse waves, thoracic respiration, electroencephalograms (EEGs), and electrooculograms (EOGs). ECGs were obtained by using CM5 instruction. EMGs were obtained by active electrodes (NM-512G, Nihon Kohden) affixed to the top of the trapezius muscle on the right shoulder. Pulse wave by the finger-prove (TL/201T, Nihon Kohden) was placed at the second finger of the left foot. Thoracic respiration was obtained by using a belt-shaped sensor (TR-512G, Nihon Kohden) rolled around the abdominal region. In addition, these signals were recorded by using multi-telemeter (WEB-9000, Nihon Kohden) and basic medical system software (QP-110H, Nihon Kohden) as 500 [Hz] of sampling frequency. The rib abdomen was used as a body ground for EMGs and ECGs.

In addition, EEG signals (F3, F4, C3, C4, O1, O2: unipolar induction, reference electrode was placed on the left earlobe A1) and Vertical EOG signals were recorded by a silver plate electrode (NE-116A, Kohden) for EEG, amplified by biological monitor (BIOTOP 6R12, NEC) with 1000 [Hz] of sampling frequency.

2.5 Data Analysis

In this paper, physiological indices for analysis were ECGs (R-R Interval, %HF, LF/HF, where, HF as High Frequency, LF as Low Frequency), EMGs (Root Mean Square: RMS), EEGs (Background Activity, β/α), pulse wave, and respiratory rates [1/s]. Trends of changes of the above physical indices were validated corresponding to the changes of mental workload by the difficulty of the tasks set on the experiment. Analysis of variance was conducted among participants as dependent variable with each of physiological indices, and independent variable as task condition. All physiological indices were normalized between the tasks on each participant to exclude influence of the individual differences. In this paper, results of EMGs were shown.

Previous research attempting to evaluate the ease of driving by instability of vehicle reported that EMGs at masseter was raised by the stress while driving with sense of anxiety [9], and EMGs were included correspondingly to the change of the level of strain by the difference of riding comfortability while driving [10]. Results of above studies showed the possibility that mental workload such as a mental stress and mental strain can be evaluated by using a change of EMGs. Therefore, in this study, it was verified whether mental workload such as mental strain while operating IVIS in particular can be evaluated by using EMGs.

Analysis of EMGs started with calculation of RMS values from raw EMG data obtained by the experiment. RMS was obtained such that a total of 100 data points, separated into half, that is, before and after the onset, were averaged into a single plot. Because participants having low averages of RMS values at all times of all tasks were considered not actively performed using the trapezius muscle for steering, these participants' muscle activities were less sensitive to the changes in mental workload. Therefore, we set a threshold value as 50% of the average RMS of all tasks on all participants, and participants that had average RMS lower than these thresholds were excluded from analysis, yielding EMG data for eight of participants were not analyzed farther. On the other hand, mental workload such as a mental strain while operating IVIS corresponded to the motions induced by perception, judgment, and manipulation of participants, hence, because factors causing mental workload to the participants could be identified by EMGs grouped by a unit of single motion, we performed data processing as follows. In this paper, we assumed three factors that influence EMGs recorded from participants, (1) presence or absence of influences from mental workload by operating IVIS, (2) differences of sensitivity to the mental workload by differences of motions of the left hand while operating IVIS, and (3) presence or absence of effects on the sensitivity as the evaluation index for EMGs by steering positions griped by the right hand. Therefore, we identified motions of participants by visual inspection with using videotaped data on the experiment, for the purpose to examine above three conditions to be the factors for affecting EMG data. We analyzed data in terms of the following three methods to clarify the relationship between muscle activity and the details of pattern of motions while operating IVIS.

(1) Comparison of EMGs while steering by the right hand when IVIS was operated, with steering with both hands before/after IVIS was operated.

Driving operations by participants were divided into "steering by the right hand when IVIS was operated, " that is, participants steered and operated IVIS in the same time, and "steering with both hands before/after IVIS was operated" that is, participants steers by their both hands without operating IVIS. We obtained muscular loads as EMGs for these two steering performances and compared for each task. If muscular loads on operating IVIS are sensitive to the differences of task conditions, differences of mental workload such as a mental strain and time pressure by operating IVIS can be evaluated by using EMGs. In addition, it is conceivable that changes in EMGs while steering with both hands can be an index to reflect general mental workload during the task.

Moreover, correlations between muscle activity while operating IVIS and, behavioral indices (miss rates for MSDT) and subjective indices (WWL scores by NASA-TLX) were evaluated as well.

(2) Comparison of muscular loads among three types of motions by the left arm on steering while the right hand for IVIS operation.

We hypothesized that the left hand motion played an important role for reflecting mental workload more sensitively, by verifying changes in EMG signals during operating IVIS. Therefore, after instructions were given to start operating IVIS, EMGs for each action were recorded. The actions can be classified into three; 'the action when participant moved his left hand to IVIS from steering wheel', 'the action when participant stayed his left hand on IVIS', and 'the action when participant returned his left hand to steering wheel from IVIS'.

(3) Differences in sensitivity of the EMGs by the location of the right hand on the steering wheel.

Differences in the location of the right hand would be considered as a potential factor for biasing EMG signals. At the time of the experiment, participants were able to steer any locations on the steering wheel. However, post-hoc observation for participants driving videos and their associated EMG signals, revealed that difference of grip positions on the steering wheel were varied by postures during operating IVIS, hence the variety of postures may affect muscular loads for the upper right trapezius, which demonstrate characteristic responses to maintain postures of the upper limb. Therefore, whether or not changes in EMGs by differences of the right hand's grip positions on steering wheel was validated. At the time of steering in the experiment, it was instructed that grip positions were set to either upper, middle, or lower position on steering wheel as shown in figure1. Accordingly, by calculating and comparing RMS-values of each grip position and on each task for each participant, we decided to examine difference of sensitivity of EMG as classified by the grip position as an index for the mental workload.

EMGs of each detailed motion for operating IVIS by obtaining results through the analysis (1) and (2), were averaged on the basis of operations and motions, and were used for evaluating mental workload. RMS values for EMGs normalized by each participant were obtained and their statistical analysis was conducted.

On the other hand, for the analysis (3), different data comparison was conducted because participants were instructed to change the grip position freely on the steering wheel throughout the experiment. Hence, there were many participants who change the grip positions several times within one task trial. Thus, average values of muscular loads by each grip position were compared among grip positions despite the differences in participants and tasks. These RMS values were standardized for each participant.

3 Results

(1) Comparison of EMG while steering by the right hand when IVIS was operated, with steering with both hands before/after IVIS was operated.

Figure 2 shows the relationship between tasks and the muscular loads of the upper trapezius when the participants perform driving steered by the right hand with IVIS operation. Because hypothesis of sphericity for muscle activities of the upper trapezius while driving by the right hand with IVIS operation was not rejected ($p=0.76$), correction of degrees of freedom was not applied. As showing in figure 2, muscular loads at the tasks with IVIS operation and the right hand-steering were significantly higher than those at the CONTROL condition ($F(3, 30) = 10.44$, $p<0.05$). Figure 3 shows the relationship between task and muscle activities of the right upper trapezius at the time from the end of operating IVIS, that is, period while driving with both hands, to the beginning of the next instruction for operating IVIS. Again, hypothesis of sphericity was not rejected ($p=0.78$), and correction of degrees of freedom was not taken into account. While steering by both hands before/after operating IVIS, there was no significant difference of muscular loads between tasks ($F(3, 30) = 0.70$, n.s.).

Positive correlation was found between behavioral indices (miss rates on MSDT) and muscular loads (RMS-values) while operating IVIS ($r=0.68$, $t(44) = 5.97$, $p<0.01$). In addition, positive correlation was found between subjective indices (WWL-point obtained by NASA-TLX) and muscular loads (RMS-values) while operating IVIS ($r=0.65$, $t(40) = 5.27$, $p<0.01$). Note that number of participants obtained for correlation between subjective indices and EMGs became 10 because omission of filling out NASA-TLX by one of participants was found after the experiment.

(2) Comparison of muscular loads among three types of motions by the left arm on steering while IVIS was operated by the right hand.

Figures 4, 5, and 6 show trends of muscular loads among tasks by differences of motions of the left arm while operating IVIS (figure 4: the left hand moves to IVIS, figure 5: the left hand stayed on IVIS, figure 6: the left hand returns from IVIS). Participants performed driving by using one hand when they operate IVIS, thus tasks targeted for comparison were following three tasks, that is, MAP, RADIO, and TEL. In addition, because hypothesis of sphericity for two conditions were not rejected (move to IVIS: $p=0.50$, stay at IVIS: $p=0.33$), correction of degrees of freedom was not applied. On the other hand, because hypothesis of sphericity for EMGs when participants returned their hand to steering wheel from IVIS was rejected ($p=0.034$), correction of degrees of freedom was applied using the Greenhouse-Geisser's method. As shown in figure 4, there were no significant differences in EMGs among different IVIS operations when participants moved their left hand to IVIS ($F(2, 20) = 0.98$, n.s.). In addition, figure 5 shows that there were no significant EMG differences among different IVIS operations when participants stayed their left hand on IVIS ($F(2, 20) = 1.83$, n.s.). When the participants returned their hand to the steer, there were marginally significant EMG differences among different IVIS operation ($F(1.31, 13.09) = 3.35$, $p<0.10$), shown in figure 6. Among them, EMGs on TEL task were significantly higher than those in MAP task ($p<0.05$).)

(3) Differences in sensitivity of the EMGs by the location of the right hand on the steering wheel.

Figure 7 shows the tendency of average EMGs on each grip location for steering by the right hand, summarized as a ground average. Figure 7 shows that EMGs when participants gripped high position of steering wheel was higher than those when participants gripped low position of steering wheel.

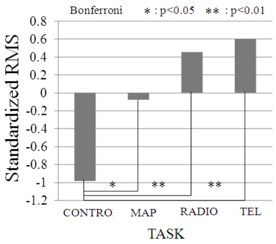

Fig. 2. Relationship between task and standardized RMS of right trapezius muscle when car navigation system was handled

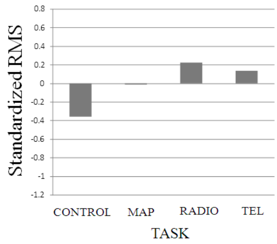

Fig. 3. Relationship between task and standardized RMS of right trapezius muscle before/after car navigation system was handled

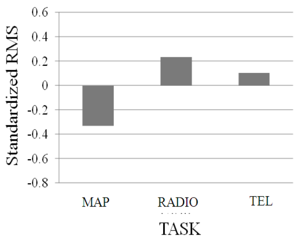

Fig. 4. Comparison of standardized RMS of right trapezius muscle between tasks while participant's left hand was moved to car navigation system

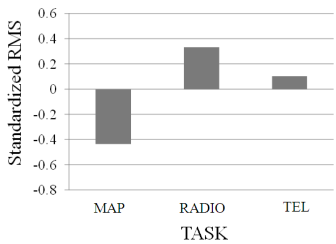

Fig. 5. Comparison of standardized RMS of right trapezius muscle between tasks while participant's left hand stayed on car navigation system

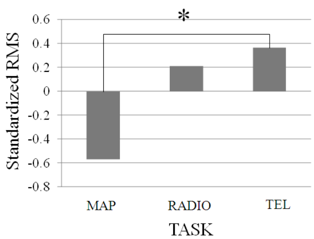

Fig. 6. Comparison of standardized RMS of right trapezius muscle between tasks while participant's left hand was returning to car navigation system

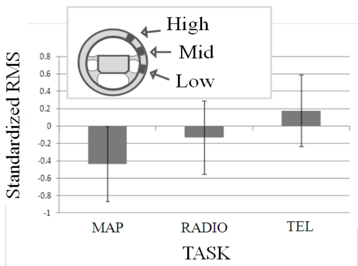

Fig. 7. Differences in standardized RMS by grip positions

4 Discussion

(1) Comparison of EMGs while steering by the right hand when IVIS was operated, with steering with both hands before/after IVIS was operated.

Muscular loads for the tasks including IVIS operation were higher than those for the task 'control', which did not require IVIS operation. High muscular loads observed in this study reflected either high mental workload caused by IVIS operation or physical workload generated by right-hand steering. Muscular loads while driving with both hands without operating IVIS showed no significant difference among tasks. Therefore, it was not clear that these muscular loads reflect overall mental workload at the driving with IVIS operation. In addition, positive correlation between behavioral indices and EMGs among tasks was observed. Therefore, measuring EMG signals while operating IVIS by performing MSDT is one of the potential methods for evaluating mental workload.

(2) Comparison of muscular loads among three types of motions by the left arm on steering while IVIS was operated by the right hand.

Muscular loads on the tasks 'RADIO' and 'TEL' were significantly higher than those on the task 'MAP', when participants returned his left hand to steering wheel from IVIS. Intention for a return to steering from operating IVIS may relate to these significant differences of muscular loads. Because participants felt these anxiety and stress and deserved to avoid such situation as soon as possible, they would have moved their left hand to steering wheel faster to steer by his both hands. Muscular strain generated by fast movement of the left hand would influence EMGs of the right trapezius. High muscular loads by the masseter, supposedly muscle strain, reflected stress and anxiety, reported by the previous study [9]. Thus, increasing tendency for muscular loads found in this experiment may reflect mental stress and anxiety as well. In addition, this anxiety may be caused by the mental stress during transition from normal steering to IVIS operation back and forth. Future study includes additional verification required for confirming participants' intention to move their left hand quickly for returning normal steering position.

(3) Differences in sensitivity of the EMGs by the location of the right hand on the steering wheel.

Muscular loads when participants grip upper part of the steering wheel was higher than those when participants grip lower part of the steering wheel. Therefore, muscular loads of the trapezius would be a potential index to reflect differences of mental workload clearly by controlling participants' posture to grip upper part of steering wheel. EMGs obtained at the trapezius was clarified to be an effective index, only if apparent EMG signals were obtained, that is, eleven participants of nineteen participants in this paper. Therefore, it is important to set configuration of environment for detecting clear muscle activities of the right trapezius by controlling the grip position on the steering wheel. In addition, it would be necessary to determine the appropriate indices by comparing EMGs of the other muscles as well. EMGs when participant returned his left hand to steering wheel from IVIS especially changed the level of mental workload by operating IVIS from the above results (1) (2) and (3). Therefore, our results clearly opened up the possibility that EMGs were a valid index for evaluating mental workload.

5 Conclusion

In this paper, we validated physiological indices which reflected levels of mental workload, that is, the effect induced by differences in the IVIS operation. EMGs reflected levels of mental workload and they showed correlation with subjective and behavioral indices. It was still marginal to infer that, possibility of using EMGs for evaluating mental workload could be demonstrated. We must identify the environment and the kind of muscle locations which reflect levels of mental workload more sensitively, and validate sensitivities of these muscles hereafter.

Acknowledgement. This study was conducted in collaboration with Osaka University. We would like to express our gratitude to collaborators, Kazumitsu Shinohara, Hiroshi Naito, and Shuhei Yoshida.

References

1. Haga, S.: Indices for assessing mental workload. Theory and measurement for mental workload, pp. 19–22 (2001)
2. Haga, S., Mizugami, N.: Japanese version of NASA Task Load Index: Sensitivity of its workload score to difficulty of three different laboratory tasks. Ergonomics 32(2), 71–79 (1996)
3. Shinohara, K., Shimada, A., Kimura, T., Ohsuga, M., Wakamatsu, M.: Assessing driver's cognitive load by stimulus detection task when a driver operates an in-vehicle information devise. In: (2012 JSAE Spring Convention) Proceedings, No. 81-12, pp. 13–18 (2012)
4. Merat, N., Jamson, H.A.: The effect of stimulus modality on signal detection: Implications for assessing the safety of in-vehicle technology. Human Factors 50, 145–158 (2008)
5. Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices, from the U.S. Federal Register, `http://www.gpo.gov/fdsys/pkg/FR-2012-02-24/pdf/2012-4017.pdf` (accessed July 31,2012)
6. Jin, H., Shimomura, Y., Iwanaga, K., Katsuura, T., Sugiura, K., Mochizuki, M.: Evaluation of the mental workload during a visual search task with working memory by various physiological indices. Journal of Physiological Anthroporogy 10(4), 33–40 (2005)
7. Ohsuga, M., Boutani, H., Shimada, A., Shinohara, K., Kimura, T., Wakamatsu, M.: Assessing driver's cognitive load by physiological indices. In: (2012 JSAE Spring Convention) Proceedings, No. 81-12, pp. 19–24 (2012)
8. Kamakura, Y., Ohsuga, M., Hashimoto, W., Lucian, G., Sato, H.: Evaluation of driver's cognitive load caused by presented information using P3 latency in eye-fixation related potential. Transactions of Society of Automotive Engineers of Japan 40(5) (2009)
9. Kuramori, A., Koguchi, N., Kamijo, M., Sadoyama, T., Shimizu, Y.: Evaluation method for vehicle handling and stability focusing on muscle tension of driver. Journal of Japan Society of Kansei Engineering 6(2), 87–92 (2006)
10. Zheng, R., Yamabe, S., Nakano, K., Aki, M., Nakamura, H., Suda, Y.: Evaluation of driver physiological nurden during automatic platooning using physiological index: development of energy-saving ITS technologies. In: (2010 JSAE Spring Convention) Proceedings, No. 7-10, pp. 29–32 (2010)