Development of a Personalized Learning System Using Gaze Tracking System

JAE-CHUL SONG, SANCHUN NAM, KI-SANG SONG[1], and SE YOUNG PARK
Dept. of Computer Education
Korea National University of Education
ChungBuk, 363-791, Republic of Korea
songjc411@gmail.com, happynsc@knue.ac.kr
[1] Corresponding author: kssong@knue.ac.kr, nubo30@gmail.com

Abstract: - Providing timely feedback is crucial for a successful personalized e-learning system. A personalized learning system with e-learning contents combined with an eye movement tracking device has been developed with an open source-based gaze tracking system. The effects of feedback delivered to learners depend upon learners' attention while gazing at the e-learning contents have been tested based on learners' academic achievement. It is found that the experimental group with feedback based on eye-movement shows higher scores than the controlled group without feedback using eye tracking devices. Also more eye fixation time and fixed point numbers appeared in learners of the experimental group than the controlled group, and thus it can be said that more visual attention was possible with the gaze tracking feedback system. These finding show that feedback using eye movement information may contribute to better interactions between learner and contents, and thus create a more effective e-learning system.

Key-Words: - E-learning, Eye-tracking, Gaze information, Feedback strategy, Academic achievement.

1 Introduction

As technology develops, e-learning has been increasingly adopted into many aspects of education. E-learning allows users access to the learning contents without the limitation of time or space. Also it provides extensive resources, and this advantage draws continued interests. Although there are numerous studies emphasizing the positive impact of e-learning, it has restrictions due to the distinct characteristics of the learning environment. In classroom situations, with teacher's presence, it is possible to observe learners' progress, and guide learners for better learning performance in real time. However, in e-learning situations, teachers and learners are separated which blocks detailed observations of learners' performance to appropriately provide assistance [1].

If it is possible to provide feedback on cognitive and emotional overload to learners during e-learning situations, e-learning can make the leap from the current limitation of distance between lecturers and learners. Thus, in this research, it is attempted to analyze learners gaze information on learning contents in order to provide appropriate feedback, by combining eye-tracking technology in an e-learning environment. The effect of feedback from gaze information on learners' academic achievement was investigated in order to broaden the idea of improving the e-learning environment.

1.1 Eye tracking technology

Eye tracking technology is technology that tracks one's eye movement continuously. It allows users to observe one's eye movement to understand one's response to the stimulation and the process of information acquisition. Various methods to track eye movement have been developed, but pupil centre corneal reflection is the most popular method [2].

The pupil centre corneal reflection method uses a camera to record infrared light which is reflected from the pupil and cornea. Since, infrared light does not influence human eye pupil size; it is used to track eye movement. Gaze is calculated by using the centre of the pupil. If the person's eye moves in various directions, the location difference occurs between the centre of the pupil and the glint. By calculating the relative location, the gaze direction can be calculated [3].

According to the position of infrared light on a human's eye, the pupil tracking method can be categorized as in Figure 1. A camera and an infrared light lamp are located in the same position; the reflected infrared light from the retina can be recorded with a camera. This method produces a bright-pupil state. If the position of the camera and an infrared light lamp is different, the reflected infrared light cannot be caught and recorded by the camera. Thus, the image recorded by the camera shows a dark-pupil state, as if the pupil absorbed the light. Since, the pupil centre corneal reflection method is vulnerable to the subject's head movement, it is important to immobilize the subject's head during the experiment.

In this research, a subject's head was fixed while the eye tracking process was activated. Also, this research chose to track the subjects' pupil status in the dark-pupil state [4].

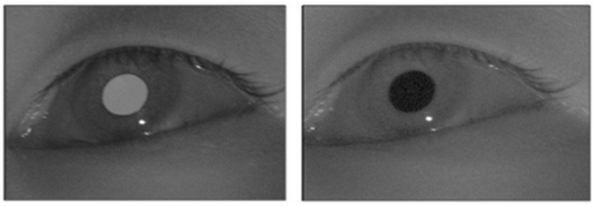

Figure 1. Bright-pupil status(left) / Dark-pupil status (right)

1.2 Eye Tracking Devices

Eye tracking technology, such as gaze tracking and eye record analysis, has developed significantly. IT University of Copenhagen developed an eye tracking device, ITU Gaze Tracker [5], with an open source project for developing a low-cost eye tracking system. Thus, ITU Gaze Tracker was used for an eye tracking device in this research, for the following reasons. Certain commercial eye trackers can be quite expensive for general purposes. While, ITU Gaze tracker allows for a cost effective system through using PC web-cams.

For the eye tracking technology, Pupil centre corneal reflection was used with infra-red lights and a camera to capture eye movement and process an image. To extract pupil area and corneal light from one's eye area, it is required that a web-cam with the infrared cut-off filter be removed and infrared LED is installed or a camcorder with night mode. Also, it is possible to enhance the pupil and corneal light tracking through attaching a visible ray cut-off filter or a printed film on a lens.

For the experiment, a USB monochrome CMOS camera by the Thorlab Company and two infrared light projectors were modified. (See, Figure 2)

Figure 2. An assembled eye tracking device

Gaze Tracker allows for eye image acquisition in two ways; head fix tracking (one eye measurement), long distance tracking (both eyes / one eye measurement). Figure 4 shows the image of pupil tracking with one eye, long distance tracking by Gaze Tracker. The red point is the pupil area and the yellow points are reflected infrared lights.

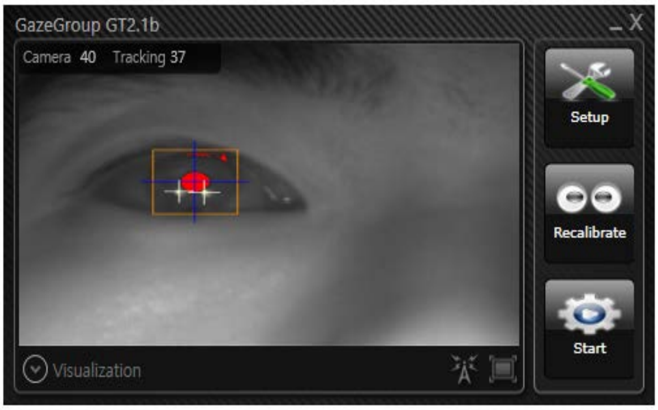

Figure 3. Pupil and glint tracking with Gaze tracker

1.3 Literature Review of Eye Tracking Technology in e-learning System

In an e-learning environment, learning contents are delivered via an electronic device such as a computer monitor. Although the e-learning environment may meet the need of growing demand for well-developed learning contents [6], there exists the need of personalized and active learning systems for learners [7].

Learners acquire knowledge or understand provided information while watching content with eye movement. Learners' eyes move with visual attention, not only simple movement. To accomplish the task learners' eyes can proactively and selectively browse contents. If learners focus on e-learning contents, it is possible to collect data from their eye movement which can help understand learners' cognitive process [8] [9].

Exploiting these characteristics of eye movement and cognitive process few researches have been reported combining eye tracking and e-learning application. The AdeLE (Adaptive e-learning with eye tracking) is one of the first papers to utilize the real-time eye tracking data for e-learning system [10]. They tried to understand learner's cognitive process with gaze tracking information. Another interesting research is e5Learning, it is a prototype e-learning system to exploit eye movements for effective e-learning. The system has the capabilities of basic user activities of provided contents, generation of additional contents based on the user's actions for providing further information, and learner's condition of emotions using physiological data from eye tracker [11]. Also eye tracking techniques have been applied for detecting learner's emotions [12], [13], and used to provide information for pedagogical agents to motivate learners [14]. Most of them explored the possibility of applying eye tracking technology into various modes of e-learning systems; more research is required to verify the effectiveness of applying eye tracking techniques into real e-learning systems with inexpensive hardware and ease of installation [15].

In this paper, we have developed an adaptive personalized e-learning system with gaze tracking capability to exploit open source software, and the characteristics of actual usability of a personalized e-learning system with eye movement has been analysed.

Since, learners' visual information can reflect, learners' learning process, it is possible to design and provide appropriate feedback during e-learning situations, by interpreting learners' visual information. For example, with eye tracking it is possible to identify the point the learners look at as well as the time learners' spend on looking at certain spots. Also, certain feedback can be provided if the learners' skip over information. Eye movement allows subtle and unburdened interactions between learners and e-learning contents. These options can assist learners to have more effective learning experiences and help lecturers understand learners learning situations concretely without being present.

Just and his colleagues [8] argue the eye-mind hypothesis, while people reading the text have their gaze fixed on a word the interpretation of the word happens simultaneously. Further, it is suggested that gaze information can provide meaningful information towards learners' cognitive process. Many studies have been conducted on eye-movement patterns to indirectly measure learners' cognitive progress, with eye-tracking technology development. According to Iqbal, et al. [16], and He, et al. [17], the pupil size can be a reliable measurement of mental overload.

Furthermore, extracting essential information to understand the writing mostly happens during gaze fixation time. It is possible to observe learners spend a longer gaze fixation time when they feel cognitive overload while they read the text [18]. Other studies also note the relation between gaze fixation time and learning achievement [19],[20]. It can be interpreted that gaze information can be used to understand learners' learning status by analysing the number of gaze fixation points and the gaze fixation time. This information can also be an effective tool to understand learner's attention on learning contents area [21].

Based on these findings, the position and the duration of gaze fixation were selected to understand learners' learning status in this research. The fixation points derived from learners' eye movements watching e-learning contents can be illustrated as in Figure 4.

The total fixation time on each fixation point is calculated to set the threshold for providing feedback. Content screens were divided to improve the accuracy of the system (see, Figure 4). Thus, learners learning area can be easily tracked by fixation points and the fixation time on certain content areas to estimate learners' attention rate and learning status.

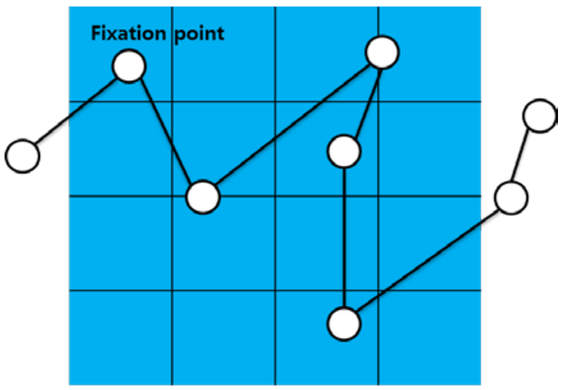

Figure **4.** Gaze movement on divided contents area

To calculate fixation time on certain learning content areas, total fixation time was used in this research. The total fixation time is the sum of all the fixation times, including repeated gaze time [22]. The lecturer set the threshold time for minimum learning time in certain learning areas, depending on the difficulty level of the contents and learners academic level. From this mechanism, it is possible to collect data to understand learners learning status, which contents learners were interested and which contents learners found difficult. Depending on the data, e-learning systems can provide further information on specific contents or check the degree of learners' understanding, and learners can be guided by feedback from the analyzed gaze information in real time.

2 Experiment Design

The major classes of ITU Gaze Tracker (GT) [5] modified to our system are depicted in Figure 5. The GT is an open-source program and linked with the Microsoft Direct X program for capturing eye-movements with a Web camera mounted on a laptop computer.

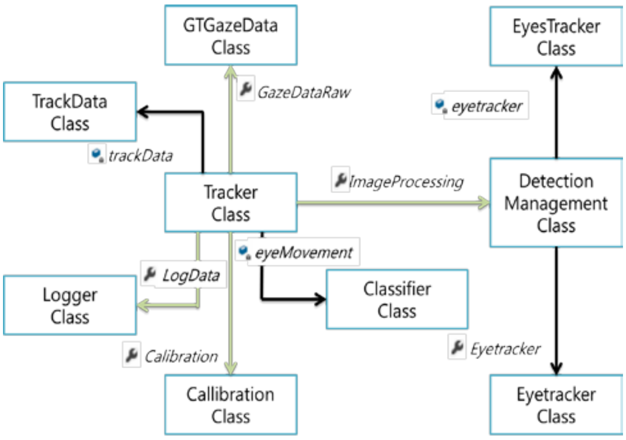

Figure 5. The S/W system structure in the eye tracking module

The research module was developed including a server and client model to analyse learner's information and provide feedback. Learning contents were developed and adapted for e-learning environments with the gaze tracker. Learners' information was collected by client and the information was analysed in a server to provide appropriate instructional feedback. With a server computer, gaze tracking module analyses the status of fixation points and fixation time and gaze analysis module decides instructional strategies and provides feedback. The structure of system module is illustrated in Figure 6.

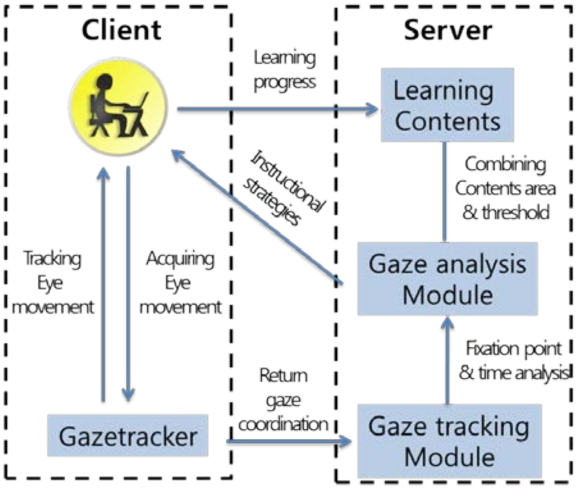

Figure 6. Overall system structure

Feedback strategies through gaze tracking information have been decided based on threshold time per each content area as in Table 1. Lecturers set the threshold time based on intended learning time and actual learning time. The lecturers then compared both learning times to understand learner's attention level. The details of feedback strategies on threshold times are described in Table 1.

Table 1. Feedback strategies with gaze information

Status	Purpose	Strategy
Under threshold	Introduce learners to corresponding areas to study again. Effective contents exploration.	Indicating signs on corresponding areas. Providing key questions.
Above threshold	A decrease of cognitive load	Providing further abridged information

The experimental system calculated fixed point information in real-time, and if the eye moves into the next paragraph or outside of the learning area and failed to satisfy the pre-set up threshold time, the feedback message guides learner's attention into the current reading area. Guidance is given as essential questions related to the current paragraph as a pop up window, and requires the learner to recognize his(her) awareness of the current learning material.

Also, if a learner does not gaze at the current learning area due to blinking or other reasons , a feedback message is given after 1.5 seconds. The reason the 1.5second time limitation was selected is based on the average of 5 times searching for 4 or 5 words of Korean [23]. Therefore if a learner gazed for more than 1.5seconds on a specific area, it is assumed that the learners attention has moved into another area and feedback message is given.

This research attempted to understand the impact of feedback strategies from learners' gaze information in e-learning situations and how it effects learners academic achievement.

2.1 Participants

The research subjects were 28 undergraduate students and 2 graduate students, 13 male, and 17 female with normal vision. Students were divided into 2 groups with 15 people in each; control group and experimental group. A prior knowledge test was performed in both groups to confirm the homogeneity between groups in terms of academic level.

2.2 Research Design

The experimental group studied using gaze information utilized e-learning contents, so they received feedback according to their eye movements. While the control group studied with the same the e- learning contents but didn't received feedback. After the experiment, academic accomplishment tests and gaze information were analysed to identify the impact of the feedback using gaze information.

2.3 Contents and Feedback Design

E-learning contents used in this experiment consisted of text and feedback. The learners are asked to read the following text from a computer screen, and their eye fixation time on certain points are tracked using a gaze tracking system.

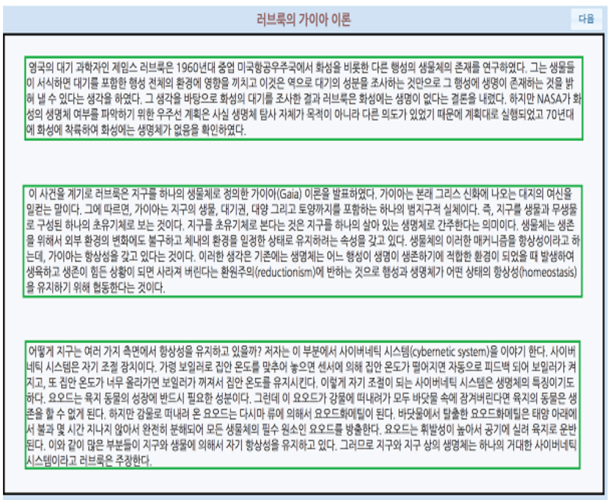

Figure 7. Text based content for developed system

According to the measured eye fixation time compared with the threshold time in Table 1, two different types of feedback were provided. The feedback strategies are asking questions if the learner spent less time than the previously set threshold time, and providing a content summary if the learner's eye fixation time exceeded the threshold time.

2.4 Procedure for Experiment

(1) Decide on an important element to estimate learners' learning situation through a literature review about eye movement characteristics and its interpretation.

(2) After selecting a learning contents topic, develop feedback strategies which is synchronized with learners' learning situations.

(3) Design and develop eye tracking technology with embedded learning contents.

(4) Measure the effect of the learning contents on learners' academic achievement, and analyse the effective factors on academic achievement.

(5) Based on the results, the author explored the validity of eye tracking technology embedded in e-learning contents.

Figure 8. Measurement equipment

3 Data Analysis and Discussion

3.1 Experimental Process

3.1.1 Threshold time setting for experimental group

The experiment started with the control group to gather an average learning time from actual learners. While the control group studied the contents, their learning time spent per each learning area was measured. The average learning time became the main reference to set the threshold time per each learning area for the experimental group.

3.1.2 Appropriateness of learning contents

Before analysing the results, the appropriateness of the learning contents was tested to secure the results objectivity. The average fixation time was compared which is shown in Table 2. According to Levene's Test for Equality of Variances**,** $F = 1.140$, $p = .295$, thus it is assumed that both populations have the same variance.

Table 2. Average fixation time (p <.05)

Group	Mean (ms)	S.D.	*t*	*p*
Experimental (N=15)	209.07	20.17	.697	.492
Control (N=15)	204.47	15.71		

Testing the appropriateness of the learning contents, we set up a null hypothesis of no fixation time difference on average between the two groups as in Table 2.

If the *p*-value associated with the *t*-test is less than the significance level (<.05), then the null hypothesis is rejected, and both groups have an average fixation time. On the contrary, if *p* value is greater than the significance level (>.05), it fails to reject the null hypothesis and both groups do not have average fixation time [23].

From observing Table 2, the *p*-value is greater than the significance level (>.05), thus we can conclude that both groups have no average fixation time difference. That means even though average fixation time for the experimental group was 209.07ms, and the control group was 204.47ms, it is safe to say that there is no difference in terms of fixation time with a significance level (*p*-value) of .05.

The average fixation time varies with the level of learning contents, thus it can be used as evidence to show that the learning contents were perceived as the same level from both groups [24].

3.1.3 Academic Achievement

To check the effect of feedback from the experimental set up, we have measured the academic achievements of both groups.

We analysed the independent *t*-test of academic achievement, because the *F*-value of both groups academic achievement test shows 0.175, and 0.697 in *p*-value from Levene's Test for Equality of Variances.

When we designed this system, we assumed that there would be a difference in academic achievement between the two groups, and thus we set up the null hypothesis that there exists no difference.

Table 3. Academic achievement results (p <.05)

Group	Mean	S.D.	*t*	*p*
Experimental (N=15)	64.67	19.95	2.989	.006
Control (N=15)	44.33	17.20		

Looking at Table 3, we can see that the mean difference of academic achievement between the two groups was 20.34, and $p = .006$, the average accomplishment results were different with a significance level of .05. Since the *p*-value is less than the significance level, (<0.05) the null hypothesis is rejected. This indicates that there exists meaningful academic score differences between the two groups. From this finding, it is reasonable to suppose that the designed feedback from gaze information has a positive effect.

3.1.4 Visual Attention Factors

The achievement differences may be explained through the fixation time spent on specific areas, and we have measured the fixation time and number of fixation points of both groups.

Table 4. Measurement results of fixation time and number of fixation points (p <.05)

Factor	Mean		S.D.		t	*p*
	Control (N=15)	Experi-mental (N=15)	Control (N=15)	Experi-mental (N=15)		
Fixation time (s)	229.08	195.27	28.63	31.76	3.061	0.005
Number of fixation points(n)	1102.00	962.93	38.40	50.67	2.187	0.037

The *F*-value of both groups visual attention factors test shows 0.023, and 0.881 in *p*-value for fixation time. The *F*-value of 0.216 and *p*-value of 0.645 for the number of fixation points from Levene's Test for Equality of Variances. Consequentially, we analysed the independent *t*-test of visual attention factors, with the null hypothesis of no differences in fixation time and the number of fixation points in visual attention factors.

Total fixation time on the learning contents area for the experimental group was 229.08s, and the control group was 195.27s. The total number of fixation points for the experimental group was

1,102.0 and the control group was 962.93. The mean difference for the total fixation time was 33.03s and for total number of fixation points was 139.06s.

Since the *p*-values of both visual attention factors are less than the significance level of .05 the null hypothesises are rejected. Consequently, it can be interpreted that the feedback strategies for guiding learners' visual attention was effective in inducing learners visual attention.

. Considering the effects of reading speed and receiving a better score due to better reading comprehension, our experiment showed similar results as reported by Underwood et al. [25]. They showed that reading speed was predicted by the number of fixations, the average fixation duration, and the duration of the final fixation upon the sentence, but there was no relationship between reading speed and ability. Also, highly skilled readers do not necessarily have fast overall reading rates [25]. Our system was designed to prevent learners from omitting important ideas, and connecting eye movement information with feedback in order to successfully direct their attention to a specific area.

4 Conclusion

An e-learning system that provides personal feedback to learners using eye movement has been developed, and its effectiveness has been tested. From the test results, it was found that the feedback derived from gaze information in e-learning situations can be effective for learners in several aspects. Since the lack of appropriate feedback methods in e-learning systems causes less effectiveness in actual learning results and very monotonous and boring in learning.

Firstly, the group with feedback utilizing the received gaze information shows higher academic achievement. This can be interpreted to show that providing feedback with gaze information positively effects learning accomplishment.

Secondly, a higher rate of eye fixation time and number of fixation points from the experimental group can be evidence to support that feedback based on gaze information can effectively guide learner's attention to specific learning areas.

However, the effectiveness of providing feedback based on under threshold and above threshold did not show a significant difference in this experiment. This indicates that further research is needed to identify the different effectiveness of various feedback strategies. Also, research on the impact of feedback utilizing an eye tracking system on a learners' cognitive overload and the appropriate intervening time for providing feedback may provide a more effective and interactive e-learning system.

5 Acknowledgements

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2012R1A1A2008560).

References:

[1] Garrison, D. Randy, *E-learning in the 21st century: A framework for research and practice*. Taylor & Francis, 2011.

[2] Poole, Alex, and Linden J. Ball, Eye tracking in HCI and usability research, *Encyclopaedia of human computer interaction*, Vol. 1, 2006, pp.211-219.

[3] El Haddioui, Ismail, and Mohamed Khaldi, Learner Behavior Analysis through Eye Tracking, *International Journal of Computer Science*, Vol. 2 No.2, 2012, pp. 11-18.

[4] Tobii Technology AB, *An introduction to eye tracking and Tobii Eye Trackers*, 2012.

[5] ITU Gaze Tracker User's Guide, http://www.gazegroup.org/software/GT_Users_Guide.pdf, Searched on May, 9, 2012.

[6] Barik, Nikhilesh and Karforma, Dr. Sunil, Risks and remedies in e-learning system, *International Journal of Network Security & Its Applications (IJNSA)*, Vol.4, No.1, January 2012, pp. 51-59.

[7] Maja Pivec, Christian Trummer and Juergen Pripfl, Eye-Tracking Adaptable e-Learning and Content Authoring Support, *Informatica*, **30,** 2006, pp. 83–86.

[8] Just, Marcel Adam, and Patricia A. Carpenter, Eye fixations and cognitive processes, *Cognitive Psychology*, Vol.8, No.4, 1976, pp.441-480.

[9] Tsianos, Nikos, et al., Eye-Tracking Users' Behavior in Relation to Cognitive Style within an E-learning Environment, *Advanced Learning Technologies, 2009. ICALT 2009. Ninth IEEE International Conference on*. IEEE, 2009.

[10] Garcia Barrios, V. M., Gutl, C., Preis, A. M., Andrews, K., Pivec, M., Modritscher, F., and Trummer, C., AdELE: A Framework for Adaptive E-Learning through Eye Tracking, Proceedings of the I-KNOW - 4th International Conference on Knowledge Management '04, Graz, Austria, 2004.

[11] Calvi, C., Porta, M., and Sacchi, D., e5Learning, an E-Learning Environment Based on Eye Tracking, Proceedings of Eighth IEEE International Conference on Advanced Learning Technologies, July 2008. ICALT '08, pp. 376 – 380.

[12] Porta, Marco, Ricotti, Stefania, and Perez, C. Jimenez, Emotional E-Learning through Eye Tracking, IEEE Global Engineering Education Conference (EDUCON), 17-20 April, 2012, pp.1-6.

[13] Haolin Wei, Haolin, Moldovan, Arthir-Nicolae, and Muntean , Cristina, Sensing Learner Interest through Eye Tracking, *Ninth IT & T Conference, Dublin*

Institute of Technology, Dublin, Ireland, 22nd.-23rd. October, 2009.

[14] Wang, Hua, Chignell, mark, and Ishizuka, Mitsuru, Empathic Tutoring Software Agents Using Real-time Eye Tracking, Proceedings of ETRA 2006 (Eye Tracking Research and Applications Symposium), March 27–29, 2006, San Diego, CA, USA, 73-78.

[15] Rosch, Jonathan L., and Vogel-Walcutt, Jennifer J. , A review of eye-tracking applications as tools for training, *Cognition Technology and Work*, Vol. 15, No. 3, 2013, pp.313–327

[16] Iqbal, Shamsi T., Xianjun Sam Zheng, and Brian P. Bailey, Task-evoked pupillary response to mental workload in human-computer interaction, *CHI'04 extended abstracts on Human factors in computing systems*. ACM, 2004.

[17] He, Xueli, et al., The eye activity measurement of mental workload based on basic flight task, *Industrial Informatics (INDIN), 2012 10th IEEE International Conference on*. IEEE, 2012.

[18] Nibbeling, Nicky, Raôul RD Oudejans, and Hein AM Daanen, Effects of anxiety, a cognitive secondary task, and expertise on gaze behavior and performance in a far aiming task, *Psychology of Sport and Exercise* Vol.13, No.4 ,2012, pp.427-435.

[19] Rayner, Keith, Eye movements in reading and information processing: 20 years of research, *Psychological bulletin* Vol.124, No.3, 1998, pp. 372-422.

[20] She, Hsiao-Ching, and Yi-Zen Chen, The impact of multimedia effect on science learning: Evidence from eye movements, *Computers & Education*, Vol. 53, No.4, 2009, pp.1297-1307.

[21] Liu, Han-Chin, and Hsueh-Hua Chuang, An examination of cognitive processing of multimedia information based on viewers' eye movements, *Interactive Learning Environments*, Vol.19, No.5 2011, pp. 503-517.

[22] Rayner, Keith, and Arnold D. Well, Effects of contextual constraint on eye movements in reading: A further examination, *Psychonomic Bulletin & Review*, Vol.3, No.4, 1996, pp. 504-509.

[23] Song, Ki-Sang, and Lee, Woo Yeol, A virtual reality application for geometry class, *Journal of Computer Assisted Learning*, Vol. 18, No.2, June 2002, pp.149-165.

[24] Yoon, Nak Yeong, and Koh, Sungryong, Eye-movements in reading easy and difficult texts, *Korean Journal of Cognitive Science*, Vol.20, No.3, 2009, pp. 291-307.

[25] Geoffrey Underwood, Alison Hubbard, and Howard Wilkinson, Eye Fixations Predict Reading Comprehension: The Relationships between Reading Skill, Reading Speed, and Visual Inspection, *Language and Speech*, Vol. 33, No. 1, January/March, 1990, pp.69-81.

[26] Oba, M. and Yamaguchi, T., A Flexible and Efficient System Development Approach for Enterprise System and Smartphone Application, *WSEAS Transactions on Computers*, Vol. 13, 2014, pp.414-420.

[27] Selvy, P. T., Palanisamy, V., and Elakkiya, S., A Novel Approach for the Prediction of Epilepsy from 2D Medical Images using Case Based Reasoning Classification Model, *WSEAS Transactions on Computers*, Vol. 12, No. 6, 2013, pp.243-254.

[28] Noh, K.-B., Song, K.-S., Nam, S. C., and Park, S. Y., The Effects of Multimedia Elements on Learning Achievements in Digital Content, *WSEAS Transactions on Computers*, Vol. 13, 2014, pp.361-367.