論 文 の 内 容 の 要 旨

論文題目「Study on 3D Gaze Measurement and Its Application to Analyze Visually Induced Motion Sickness in Stereoscopic Environment」

（立体視環境下での三次元視線計測とその映像酔い分析への応用に関する研究）

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This doctoral thesis presents a study on 3D gaze measurement and its implementation to analyze visually induced motion sickness (VIMS) in stereoscopic environment. One important safety issue in stereoscopic environment is VIMS. VIMS is a condition in which users of dynamic 3D contents feel symptoms of nausea, dizziness, or visual fatigue during or after exposure while they are being physically still. In this study, I present a novel 3D gaze tracking method with simpler 3D calibration technique. The proposed 3D gaze tracking system, along with electrocardiography (ECG) and simulator sickness questionnaire (SSQ), are used to investigate VIMS during exposure of dynamic 3D contents.

Chapter 1 contains background, purposes, and scientific contributions of this study. Decoupling of accommodation and vergence in viewing mechanism during dynamic 3D contents is one contributing factor of VIMS. Since vergence provides veridical depth in- formation, investigation of human gaze in not only horizontal (X) and vertical (Y), but also in depth direction (Z) is important. Previous studies of VIMS used SSQ as subjective measurement. Objective measurement was performed using ECG and 2D gaze tracking. However, there was no research work that investigated relationship of 3D gaze, ECG data, and SSQ during VIMS occurrence. Furthermore, gaze tracking systems in previous studies were not compatible with active shutter glasses. Thus, the purpose of this study is to develop a novel 3D gaze tracking system that is compatible with active shutter glasses. The developed 3D gaze tracking system, ECG system, and SSQ information are used to investigate VIMS in stereoscopic environment.

Chapter 2 explains theory of stereoscopic environment, depth perception, and contributing factors of VIMS. To achieve 3D experience, human brain perceives left and right image as a single image. This mental ability of the brain to perceive two slight different images and extract depth information from them is called depth perception. Motion sickness is generally induced by vestibular stimuli while vision can also be a contributing factor. On the other side, VIMS occurs strictly caused by visual factor without vestibular stimulation.

Chapter 3 elaborates the development of 3D gaze tracking system, including design consideration, algorithm, and experimental validation. Optimized geometric method with only three calibration points in 3D calibration session is used to compute 3D point of gaze accurately. Experimental validation was performed to confirm accuracy of the proposed 3D gaze tracking system. The results show that the proposed 3D gaze tracking algorithm achieves better accuracy than conventional geometric method by average errors 0.83, 0.87, and 1.06 cm in X, Y, and Z direction, respectively. Comparison of the proposed 3D gaze tracking system with subjective judgment in depth measurement is also explained.

Chapter 4 presents a novel investigation of VIMS using the proposed 3D gaze tracking system, ECG, and SSQ in two different dynamic 3D contents containing low and high dynamic motions stimuli, respectively.

Two-way statistical Analysis of Variance (ANOVA) on SSQ data shows that nausea and disorientation symptoms increase as amount of dynamic motions increase (nausea: $p<0.005$; disorientation: $p<0.05$). To reduce VIMS, ECG data suggests that user should perform voluntary gaze fixation at one point when experiencing vertical and horizontal motions in dynamic 3D contents. Observation of 3D gaze tracking data reveals that depth gaze is compressed by sustained forward motion. This finding may strengthen visual fatigue and VIMS caused by decoupling of accommodation and vergence in dynamic 3D contents. Furthermore, user who experiences VIMS tends to have unstable depth gaze than ones who does not experience VIMS.

Chapter 5 contains conclusion, implications of this study, and future works. In this study, I present a novel 3D gaze tracking system with simpler 3D calibration that is compatible with active shutter glasses. I demonstrate that detection of VIMS in stereoscopic environment can be done by observing 3D point of gaze using low frame rate consumer-grade cameras (± 25 Hz). Experimental results show that horizontal and vertical motions are effective contributing factors of VIMS. Controlled gaze fixation during provoking scenes should be performed to reduce VIMS. Intense oscillation of depth gaze during provoking scene can be used as indicator of VIMS occurrence. The most important contribution of this study for general society is promoting methods for development of user-friendly 3D contents that considers safety issues and human factors. Based on this study, further development of mobile 3D gaze tracking system that allows free head movement is possible to expand functionality of the 3D gaze tracking in large screen immersive virtual environment.