Developing an evaluation system of visually induced motion sickness for safe usage of moving images

— Fermentation of a social understanding to supply secure and comfortable images through integration of researches on human characteristics, image analysis technique and image production technique —

Hiroyasu UJIKE

[Translation from *Synthesiology*, Vol.3, No.3, p.180-189 (2010)]

We have developed an evaluation system of moving images by estimating temporal variations of discomfort levels of visually induced motion sickness (VIMS) caused by the images. The system is useful for making image producers understand the importance of reducing the possibility of VIMS. This activity will provide an environment that allows people to use moving images at ease in a variety of fields, such as entertainment, education and medical services. The system was developed by the collaborative research of image analysis, image producing and measurements of biomedical effects to apply the basic characteristics of VIMS for evaluating general images.

Keywords : Image safety, visually induced motion sickness, biomedical effects, moving image evaluation, moving image guideline

1 Introduction

Visually-induced motion sickness (VIMS) is a condition where the following symptoms occur when a person views a moving image that contains certain motions relatively frequently.[1] The symptoms include those of motion sickness (or so called travel sickness) such as dizziness, sweating, drowsiness, increased salivation, facial pallor, stomach awareness, nausea, and vomiting. While the innovative development of recent image media technology has dramatically advanced the possibilities of moving images, it also harbors the increased risk for the viewers who may suffer from VIMS, and quick measures must be taken.

The leading theory for the cause of motion sickness is the sensory rearrangement theory[2] that proposes that the symptoms occur when the relationships among different kinds of sensory information, such as the visual and vestibular information pertaining to the body motion, differ from the ordinary situation of the body, and this discrepancy can be implicitly sensed as abnormality. A similar idea can be applied to VIMS. For example, the sickness may develop when the viewer is shown moving images as if the body is moving through space, though the actual body is static as one sits in the chair. More specifically, the sickness may be caused by the lack of vestibular perception caused by acceleration and the lack of tactile perception of the change in pressure from the contact with the chair surface, while the visual perception of body motion is presented.

With the development of the recent image media technology, computerized systems have been introduced into the production of moving images. With the wide spread of small, high precision digital video cameras, the expression of moving images with dynamic and vigorous scenes can be created. Also, large, high-precision displays habe become available in homes, and people can enjoy viewing dynamic and realistic images. However, motions in such images may be perceived as physical motion information. Therefore, if no measures are taken, viewers may develop VIMS, and rapid measures are necessary.

Recently, occurrences that are thought to be cases of VIMS have been reported in the news. For example, in July 2003 at a junior high school in the Shimane Prefecture, 36 of the 294 first grade students who were watching a video on a large screen at a lecture hall for their class developed sickness and were sent to a hospital for treatment.[3] The video image was shot by a hand-held camera, and the erratic movements that occurred frequently in the film are thought to have caused VIMS. A very similar case occurred in a school in the Mie Prefecture on November 2006.

VIMS may have greater effect than originally considered. In general, the symptoms may cease in a relatively short time by stopping the viewing in case of relatively mild cases, while for some people and under some conditions, unbearable symptoms may continue for the whole day. Such symptoms may be dangerous depending on the work in which the

Human Technology Research Institute, AIST Tsukuba Central 6, 1-1-1 Higashi, Tsukuba 305-8566, Japan
E-mail: h.ujike@aist.go.jp

Original manuscript received January 5, 2010, Revisions received June 1, 2010, Accepted June 2, 2010

person engages, and people who experience motion sickness in aircraft simulators are banned from flying the aircraft for 24 hours after the simulator training.[4]

With the advancement of image technology, the moving images are now used widely in various fields such as education, medicine, and welfare. To ensure many people can enjoy the benefits, the provision of the environment that prevents the occurrence of undesirable biomedical effect of moving images such as VIMS is mandatory and urgent. AIST created the term “image safety” as a concept to realize this, and is promoting the creation of a moving image guideline and is engaging in the international standardization activity.[5] Image safety is not only important for the user of the moving images. For the Japanese image industry to advance steadily, image safety should be like the wheels of an automobile that works alongside the development of the image technology, and is absolutely necessary from the viewpoint of the people of image industry. Therefore, image safety is an issue that must be tackled with the cooperation and mutual understanding of the people of the image industry such as the production companies, image distributers, and image display device developers. Through joint research conducted under close cooperation and collaboration among external research organizations such as the universities and industry people, the author engaged in the R&D for the VIMS evaluation system, the tool to provide the solution. In this paper, I describe the necessity of the VIMS evaluation system and discuss the research scenario that led to the development.

2 Background of the R&D

2.1 Motivation that led to the R&D

To reduce the possibility of VIMS, it is necessary to create a guideline based on objective findings related to the factors that cause VIMS and the degree of effect of VIMS. However, guidelines may not be sufficient. A guideline basically has no binding power even if it becomes the international standard of the International Organization for Standardization (ISO).

For the guideline to be effectively utilized, it is necessary to create and review the guideline under the cooperation of the parties involved in production and distribution such as the image providers that use the guideline. There are a few points that must be considered. First, the image provider needs to understand that some effects of VIMS cannot be neglected. In general, many people may consider VIMS as a minor problem and whatever measures may be taken lightly. However, over 10 % of the students had to receive hospital treatment in the case of Shimane junior high school mentioned earlier,[3] and it may be dangerous for people to engage in certain works immediately after viewing. Second, sufficient consideration must be given to the freedom of expression and freedom of artistic creativity. Guidelines and international standards are often taken as agents that limit the art of image production, and the image providers are concerned that they may unjustly threaten the freedom of expression and artistic creativity. It is necessary to make considerations so people would not reject image safety. The following methods may be useful.

(1) Prior to the creation of the image guideline to reduce VIMS, the importance of image safety including VIMS must be communicated in various ways.

(2) A method that enables the image provider to specifically check the degree by which VIMS may occur by viewing certain images is developed, and this tool is used to raise the awareness for VIMS.

While issue (1) deviates from the topic of this paper, issue (2) is the origin from which we developed the VIMS evaluation system described in this paper.

2.2 Necessity of R&D

The VIMS evaluation system is a system to evaluate the degree of VIMS that may occur in people who view certain images. By entering the image that one wishes to evaluate, the degree of VIMS that may occur in the viewer is displayed as variation over time. This system is essential from the perspective of having the image providers understand the seriousness of VIMS and to reduce the occurrence of VIMS by utilizing the image guideline that will be created in the future (Fig. 1).

First, the system will be the tool that enables the image providers to specifically understand the degree and

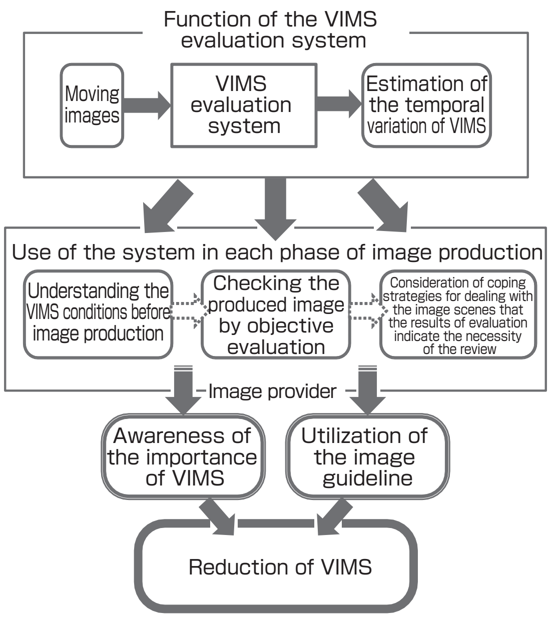

Fig. 1 Effect of use of the VIMS evaluation system on reduction of VIMS

the condition under which VIMS tends to occur. The understanding of VIMS is expected to deepen, if the degree and the temporal variation of VIMS that are generally difficult to understand are made “visible” by repeated investigation of various images using the system.

Second, this will be a method for objectively evaluating the image that will be produced or distributed by the image providers. Since there are individual differences in the susceptibility to VIMS, as discussed later, and people are likely to adapt, it is difficult to evaluate by having certain individuals view images. Therefore, a system that allows objective evaluation of images is necessary.

Third, this enables the specific measures to be taken for the images created by the people involved in the production. If the degree and the time when VIMS is likely to occur are known, the images can be edited based on such information. Therefore, it provides a method for realizing image safety.

In the creation and standardization of the guideline, the VIMS evaluation system can be a powerful tool to verify the effectiveness of the guideline. In the discussions at ISO,[6] the author has been working on the strategy of international standardization of the guideline based on the basic data obtained using the simple visual motion (see subchapter 4.1). This system is essential to show that the guideline based on the basic experiment data can be applied to general images that contain complex visual motion. Also, in the standardization discussion, an unnecessarily strict standard based on ideals may be suggested, but such standards may not be followable in reality. This system eliminates such useless standards and helps to create a guideline that can be followed practically yet fulfills the minimum requirements, by evaluating the images under various conditions. Moreover, this system provides the method for checking the compliance by the image providers themselves with the image guideline after it is issued. By analyzing and evaluating images using this system based on the guideline and “visualizing” the degree of VIMS for individual images, the policy for production and editing will be easier to establish.

We had opportunities to communicate the information on the VIMS evaluation system to the people of related industries in various occasions, and we received voices from many people that they wanted to try it. For example, the reduction of VIMS is actually a concern of the image producers, and while they think they understand from experience how to limit certain motions, they would like to check objectively. Therefore, VIMS evaluation system is highly in demand by people who understand the importance of reducing VIMS.

3 Scenario of the R&D

The development of the VIMS evaluation system was done as the “Feasibility Study for the Development (FY 2006; realization in FY 2007) of the Visually-Induced Motion Sickness Guideline Verification System” by the Japan Electronics and Information Technology Industries Association (2006~2007), as a subcontract of The Mechanical Social Systems Foundation.[7] In the R&D committee, image media companies and filmmakers who were interested in VIMS as well as the university researchers of biomedical effect gathered, and we were able to obtain cooperation from their respective standpoints through specific collaborations and joint research in the actual execution of the R&D. For example, as will be explained later, there were cooperative efforts in speeding up the visual global motion analysis essential for the system, and the production of images that readily causes sickness by the image producers. Through such cooperative efforts, we were able to develop a highly effective VIMS evaluation system that surpassed the initial goal.

The composition of the system is shown in Fig. 2. Of the components, the VIMS evaluation model involves the output based on the results of measured biomedical effects using the simple visual global motion,[8]-[10] and it does not necessarily guarantee an immediately adequate output for general images in which the visual global motion are complexly mixed. Therefore, it was necessary to calibrate the estimated results of VIMS with the actual biomedical effect measurement, and the following procedures were employed for the R&D (Fig. 3).

(1) The whole system is configured.
(2) The images that readily cause sickness are prepared. These are entered into the system to obtain the evaluation results, and at the same time, the biomedical effects are measured in a viewing experiment using the same images, and the two results are compared.
(3) Based on the comparative results, the components of the system are improved to increase the accuracy of the

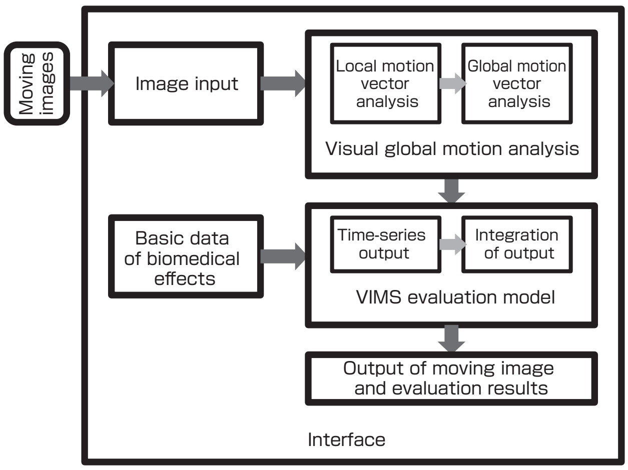

Fig. 2 Configuration of the VIMS evaluation system

Table 1. Factors that affect VIMS

	Primary factor	Details	Secondary factor	Details
Image contents	Global motion	Type of motion, velocity, temporal frequency, amplitude	3D space	Binocular stereopsis, consistency of perspective, presence of depth hints
			2D space	Spatial frequency component, luminance, contrast, chromaticity
	Local motion	Spatial distribution of velocity, temporal frequency, amplitude	Temporal	Presentation period, Prior information
Image presentation condition			Spatial	Viewing distance, environmental illuminance, display size, spatial resolution, ranges of luminance/contrast/chromaticity, binocular stereopsis
			Temporal	Temporal resolution, portability of display (temporal position change)
Viewer attribute			Perception system	Characteristics of vestibulo-ocular reflex and optokinetic nystagmus
			Sensitivity	Sensitivity to motion sickness
			Others	Gender, age, attitude of viewing, posture

evaluation.

(4) Return to (2) and repeat.

(5) After going through (4) a certain number of times, the trial of VIMS evaluation system is done by the image industry people. The usability of the user interface is improved based on the questionnaire.

Depending on the progress of the R&D, the method of constructing the system based on sufficient investigation using various images for the characteristics of the sickness caused by general images can be taken. However, since there are several image factors involved in VIMS and there is a time-series effect, numerous images with combinations of multiple conditions will be necessary to clarify the essential factors. Moreover, considering the effect of individual differences, many subjects must participate in the experiment. Therefore, the number of experiments will be considerable, and the execution will become impractical. From such considerations, to construct the system quickly for this R&D, we employed the method of constructing the system based on the basic characteristic of the VIMS found in the basic experiment and then improving the evaluation accuracy of the system using general images that readily cause sickness.

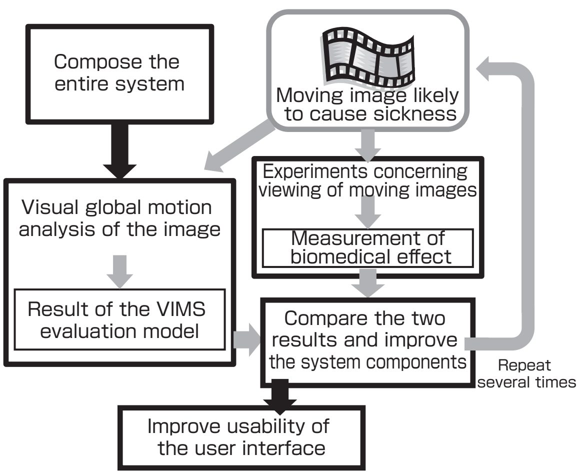

Fig. 3 R&D procedure for the VIMS evaluation system

4 Technological elements and issues

The four technological elements and issues selected to execute the R&D of the VIMS evaluation system are as follows. The relationships of these elemental technologies in the system construction are shown in Fig. 4.

(1) Findings pertaining to the biomedical effects of visual global motion

(2) Visual global motion analysis of the images

(3) VIMS evaluation model

(4) Production of images that readily cause sickness based on the image production method

(5) Measurement of biomedical effects to increase the accuracy of the VIMS evaluation model

4.1 Findings on the biomedical effects of visual global motion

While there are several factors that affect VIMS, the first factor that should be the subject in constructing the VIMS evaluation system is the visual global motion. Visual global motion is the whole set of motions that occur in the major portion of the visual field, and basically it is the visual motion within the visual field that occur by the relative motion of the body of the observer and the surrounding environment. Therefore, when the visual global motion is displayed in the large field, the observer perceives it as if he/she is in motion. The relative motions of the observer and the surrounding environment include the translational and rotational motions in the yaw axis (up-down vertical direction), the pitch axis (left-right horizontal direction), and the roll axis (to-and-fro horizontal direction) in the Cartesian coordinate system with the observer at the center. Therefore, the corresponding motions can be considered in the visual global motion.

The factors of VIMS can be categorized into image content, image display condition, and viewer attribute, as shown in Table 1, as well as the primary factors that trigger VIMS and the secondary factors that strengthen or weaken it. According to this table, the primary factor that triggers VIMS is the visual global motion categorized as the image contents. The basis is the sensory rearrangement theory mentioned earlier, and more specifically the visual global motion that is given when the body is actually static becomes the motion information, and causes discrepancy between the sensory information from the somatic and vestibular sensory systems and thereby causes sickness.[2] Therefore, in the VIMS evaluation system, the findings from biomedical effects pertaining to the visual global motion were selected as the primary component.

The basic characteristic of the biomedical effect by visual global motion was studied by the author *et al.* in the "Standardization of the Image Safety Evaluation Method (FY 2003~2005)," a Standardization Certification R&D Project, Ministry of Economy, Trade and Industry. The author *et al.* set up a virtual room by CG where the observer stood in the center of that room. The three axes (pitch, yaw, and roll axes mentioned earlier) were set with the observer's head in the center, and the observers were shown the CG moving image in which the reciprocating rotational motion (oscillation) around each axis occurred. The size of the image was 82 deg × 67 deg, duration about 1 minute, and the observer was asked for a subjective evaluation pertaining to VIMS on a 11-point scale. Two types of amplitudes (30, 90 deg) and six types of temporal frequencies (0.03, 0.06, 0.12, 0.24, 0.49, and 1.0 Hz) were used as the conditions for the reciprocating rotational motion around each axis. As a result, as shown in Fig. 5, the effect of VIMS was dominated not by the temporal frequency of the visual global motion in the image but mainly by the velocity component.[10]

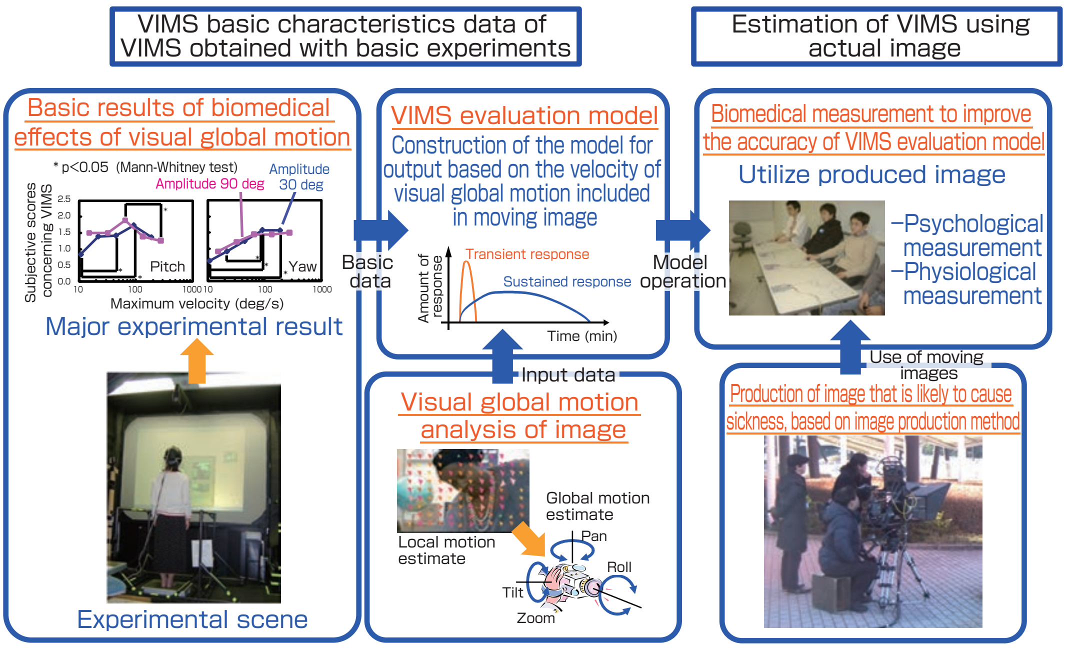

Fig. 4 Relationship of the elemental technology in the VIMS evaluation system

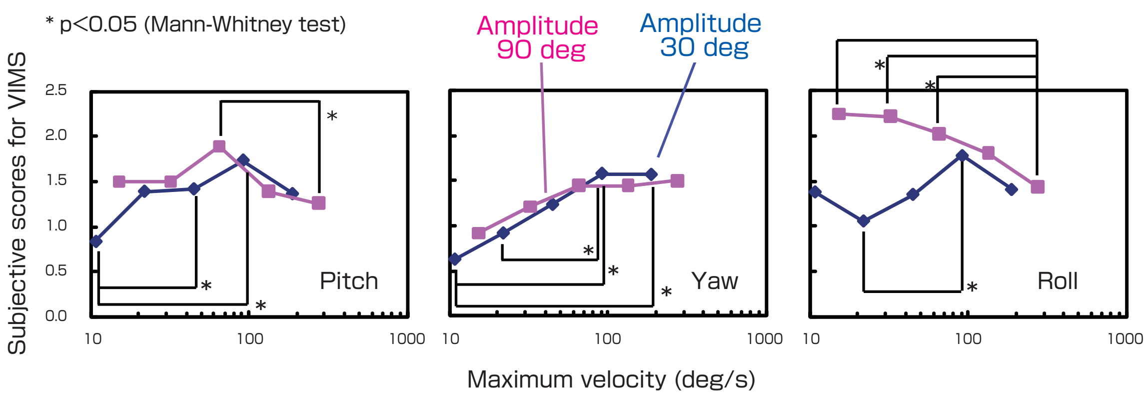

Fig. 5 Effect of the visual global motion on VIMS

Therefore, the biomedical effect occurred when the velocity of the visual global motion in the image was in the range where the biomedical effect level shown in the vertical axis in Fig. 5 reached a certain level.[11]

The point to notice in the VIMS experiment is the adaptation effect to the VIMS, and to reduce the effect, it was necessary that the participant of the experiment took at least a two-week interval before participating in the next experimental session. The combination condition in Fig. 5 is when the adaptation effect was minimized as much as possible, but with over 40 participants and with the requirement of keeping two-week intervals between sessions, over half a year was necessary to obtain the results.

4.2 Visual global motion analysis of the image

If the types of visual global motion and the temporal variation in the image subject to evaluation are clarified, it will be possible to evaluate the degree of VIMS that may be induced, based on the findings in the previous section. Therefore, in the VIMS evaluation system, it is necessary to analyze the visual global motion of the subject image, extract the components and the speed of motion contained in the image, and to calculate the temporal variation of speed. The researches of the image compression technology can be applied to realize the above.[12] Therefore, we selected this technology as the compositional element of the VIMS evaluation system, and had people and companies that specialized in the image compression technology participate in the R&D phase.

There are two phases in the process of the visual global motion analysis technology. In the first phase, the image region is divided into, for example, 16 rows × 16 columns, and the place to which each region transferred in the next frame is searched by pattern matching. The amount and direction of transfer are calculated as the motion vector (local motion vector = LMV) of each region. In the second phase, the LMV component of each region is subject to cluster analysis, and the global motion vector corresponding to the basic motion of the camera such as pan, tilt, roll, or zoom is calculated. This corresponds to the visual global motion in this system.

The issue of trade-off between the analysis time and analysis accuracy must be considered for this visual global motion analysis technology. In the initial phase of the system construction, about 15 second analysis time per frame of image was necessary, since we increased the accuracy of the system as a whole by incorporating the method with highly accurate motion analysis to improve each technological element. However, considering practical use, it was desirable that the speed of analysis be about the same as the replay time. Therefore, in the final stages of the development, we improved the method of LMV calculation to reduce the analysis time, and also checked that there were no practical issues in the analysis accuracy, and realized the practical analysis technology for visual global motion. This analysis technology was realized by Hitachi Consulting Co., Ltd.

4.3 VIMS evaluation model

In the VIMS evaluation system, the core part was the input of the temporal variation of speed and the types of the visual global motion in the image, and the output was the temporal variation of the degree of VIMS that may occur.[13] Since the assumption based on the basic characteristic of VIMS was necessary between the input and output, we created the VIMS evaluation model to realize this. The VIMS evaluation model was important in the following two perspectives.

(1) While this system assumes the temporal variation of the degree of VIMS, there is no temporal factor included in the findings of biomedical effects explained in subchapter 4.1. Therefore, it is necessary to consider the effect of the display time of images to construct a model including this factor.

(2) While this system aims for the estimation of VIMS in general images including the complex visual global motion, the findings of biomedical effects explained in subchapter 4.1 use simple visual global motion only. It is necessary to investigate whether it is possible to estimate the degree of VIMS in general images using this basic finding.

Therefore, from the perspective of (1), we investigated the variation of discomfort due to VIMS when the speed of visual global motion in the image is included in the speed range that may cause VIMS. As a result, it became clear that, due to the existence of the visual global motion that corresponded to that speed range,[13] there were transient responses in which discomfort increased in a short time, and sustained responses where the discomfort did not decrease for a while even after the disappearance of the visual global motion. Therefore, in the VIMS evaluation model, the transient and the sustained responses are output when each type of visual global motion are included in the corresponding speed range for a certain time.

Next, from the perspective of (2), to increase the accuracy of the VIMS evaluation model, the image introduced in subchapter 4.4 as likely to induce VIMS was prepared to calculate the temporal variation of the degree of VIMS by using the VIMS evaluation model. Then, the biomedical effects were measured by having the participants view the image using the same image in the procedure explained in subchapter 4.5, and the two results were compared. The parameters of the VIMS evaluation model were adjusted based on the results.

4.4 Production of images likely to cause sickness based on the image production method

For the images that contain the potential factors of VIMS to be used in improving the accuracy of the VIMS evaluation model, the production was subcontracted to the image producers who are experts of image production. For the production of such images, it was possible to use the CG images of simple contents containing complex visual motion or live-action images that were shot by the researchers, but these might not be necessarily acceptable to the experts of image production. For example, a non-expert image that contains potential factors of VIMS may not necessarily contain the visual effects and methods that are utilized by the experts, and may not be convincing to the image producers. This is not necessarily easy to explain in terms of logic, and is beyond the bounds of technological discussion, but it may be an important point in gaining understanding and cooperation on the image safety from the image industry people.

As conditions for the image production, in addition to the inclusion of potential factors of VIMS, the condition was the use of live-action images that could be assumed as the actual subject of evaluation. In the former perspective, to investigate the effect of the motion speed of pan, tilt, roll, and zoom that are basic motions of the camera, we attempted to include those potential factors based on the findings pertaining to the basic characteristic of VIMS. However, they had to be live-action images from the latter perspective, and the speed of the motion of the camera was difficult to measure at the shooting session, and the following procedure was used upon discussion with the image producer. First, five-step speed was set for each of the basic camera motion. Specifically, for pan, tilt, and roll, the settings were: very slow 7.5 deg/s, slow 15 deg/s, medium 30 deg/s, fast 60 deg/s, and very fast 80 deg/s. In case of zoom, the magnifications (and reductions) between the frames were: very slow 1.15 (0.86), slow (1.30 0.77), medium 1.50 (0.67), high 1.75 (0.57), and very fast 2.00 (0.50). Next, these speeds were held constant by special effects (SFX) shots, and motion was in one direction for the first 8 seconds, in the opposite direction for the next 8 seconds, and the basic image of 16 seconds in both directions was created. Since there were five-step speeds for the four types of basic movements, there were a total of 20 types of images. The motion of the camera used in shooting each scene was matched with the motion of the camera of the respective basic images, so the final live imagery contained the scenes that corresponded to each speed expressed in 20 types of basic images.

The important point in these images was that the participants of the experiment could view the images without becoming bored during the experiment, and so a minimum plot was added to the image. However, it was necessary to keep the plot to a minimum to prevent the story from providing emotional effects that may affect the biomedical measurements. Therefore, the cooperation of the image producer was essential.

4.5 Biomedical effect measurement to increase the accuracy of the VIMS evaluation model

In the biomedical effect measurement for VIMS, in general, there are psychological measurements that rely on subjective evaluation and the physiological measurements that investigate the effect on the autonomous nervous system. In the previous researches, the emphasis was mainly on either one of the measurements, and there was hardly any investigation on the relationship of the two measurements for temporal variation of VIMS. However, subjective evaluation requires supportive evidence of objective data as much as possible, since there is an issue of propensity in the individual differences. On the other hand, in physiological measurement, it is necessary to match with the subjective evaluation to investigate what the variations in the measurements indicate. Therefore, the two measurements were mutually essential to increase the reliability of the measurement data of VIMS.

In the development of the VIMS evaluation system, the psychological and physiological measurements were conducted simultaneously, and the investigations were done for the relationship of the temporal variation of the two. For the physiological measurement, we obtained cooperation of the Tohoku University, Niigata University, and Fukushima University that had plentiful experiences in developing the measurement method, and we investigated the relationship of the temporal variation of the subjective evaluation and the physiological indices during the image viewing.[14]-[17] To execute this experiment, common experimental protocols were used and the measurement data were shared among the above universities and AIST, and this enabled efficient collection of data from several experimental participants. Through such biomedical effect measurement, the Tohoku University and Fukushima University showed that the ρ_{max}, which is the maximum cross correlation function between the blood pressure and heart rate, changed with about 1 minute gap along the temporal variation of subjective evaluation, and that it was possible to estimate the temporal variation of subjective evaluation using the multiple physiological indices obtained by the measurements of electrocardiogram and photoplethysmogram.[14][17]

In the VIMS evaluation model, as discussed in subchapter 4.3, the specification was that it would output the transient and sustained responses each time the visual global motion was included in the corresponding speed range for a certain time. For the output of the model, the accuracy was improved by approximating it to the impulse response function estimated from the time-series data of the biomedical effect measurement conducted using several images explained in subchapter 4.4. The subjective evaluation measured every 1 minute was used as the time-series data of the biomedical effect measurement, but since it was possible to estimate the temporal variation of subjective evaluation value through multiple physiological indices as mentioned above, this VIMS evaluation model was also supported by the physiological measurement indices.

5 Linkage of the technological elements and the evaluation

5.1 Characteristic of the linkage of technological elements

We constructed the VIMS evaluation system though the combination of technological elements in the previous chapter (Fig. 6). This evaluation system was software built mainly by Fukushima University. By linking the technological elements, this system has the characteristics shown below.

First, the configuration enables the improvement of accuracy only by integrating and linking the individual technological elements. Therefore, it is possible to include the effect of viewing environment condition that cannot be ignored as secondary factor, independent from the effect of visual global motion that is the primary factor of VIMS. The viewing environment condition includes the display size of the image, viewing distance, brightness level, and luminosity of the surrounding. In fact, attempts were made to see the effect of the viewing environment by conducting biomedical effect measurements using the same image while changing these conditions and then modifying the output of the system based on the results.

Second, a list of the time period and types of visual global motion of the images that may trigger VIMS was made, and it became possible to evaluate the degree of VIMS in the case where such motions were not included. In the VIMS evaluation model within this system, certain responses (transient and sustained responses) are output each time the speed range in which the visual global motion is present during a certain time in the image. Therefore, the effect of those visual global motions can be checked by cutting off the corresponding outputs from the model. Using this function, it is possible to check the effect of the reduction of VIMS while the image producer edits the scenes that may have effect.

5.2 Evaluation of the system

For the purpose of increasing the usability of this system, we conducted a trial questionnaire with the cooperation of the parties involved at the R&D committee discussed in chapter 3. The subjects of the questionnaire were 12 people of the image industry. According to the result of the questionnaire, the analysis speed and display received overall good marks. However, there were comments that the displayed terms were too technical and hard to understand, or that the contents of the display were difficult. Therefore, we made improvements such as using simple terms, adding glossary in the manual as needed, and improving the display content.

6 Future development

The VIMS evaluation system is a prototype at this point, and we plan to increase the accuracy and usability through accumulation of trial questionnaire surveys. Also, the evaluation for the degree of VIMS is matched to the average value of the biomedical effect measurement. The large data

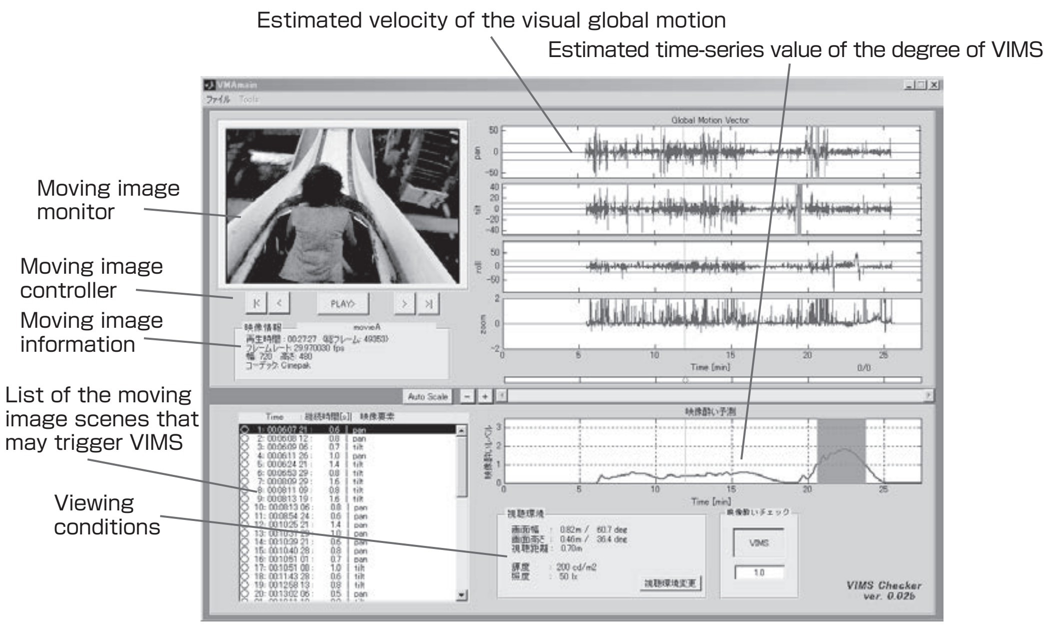

Fig. 6 Control window of the VIMS evaluation system

for over 200 participants in the experiment were accumulated for this system using live-action images, and we shall continue to estimate the percentage of people who show certain symptoms, and to estimate the level of symptoms that certain percentage of people may experience.

The international standardization of image safety is in progress as mentioned in the beginning, and the ISO standard proposal is considered for the VIMS guideline within 2010. Before the proposal is submitted, we shall promote the understanding for the VIMS issue by distributing this system to the image industry people, and we also plan to utilize this system to demonstrate the adequacy of the proposed standard in the standardization committee.

Moreover, we plan to expand this system to develop the 3D image evaluation system that enables the evaluation of 3D image safety. Since there is visual fatigue that occurs uniquely with 3D images, it is necessary to take sufficient measures against VIMS due to the increased realism of the images.

A solid 3D market is being formed with the hit of the Hollywood 3D movie in 2009 and the launch of 3D TV in 2010. In such a situation, the 3D image guideline and the abstract journal that will be the basis of such guideline were published by the collaboration of the 3D Consortium, Japan Electronics and Information Technology Industries Association, and AIST in April 2010. As a result, the social recognition for 3D image safety spread rapidly in a short time through various mass media. This was because the human network that was nurtured in the R&D for the VIMS evaluation system and its long process functioned effectively, the R&D process could be easily developed and applied to 3D images, and the passage to the activities for 3D image safety was formed as the collaboration and cooperation led to the understanding of the government organizations and various parties involved.

The 3D images have been said to have a 10-year cycle of rise and decline, but the main reason they failed to develop sufficiently in the past market is because the measures to reduce the discomfort caused by 3D images were insufficient. In the future, with the close collaboration with the external research institutes such as the universities and the industry people, we plan to increase the understanding of the biomedical effect of 3D images by joint R&D for a highly reliable 3D image evaluation system that is the expansion of the system discussed in this paper. At the same time, we would like to solve the issue of 3D image safety by enabling the evaluation of the 3D images.

Acknowledgement

Part of this study was subsidized by JKA through its Promotion funds from KEIRIN RACE and was supported by the Mechanical Social Systems Foundation and the Ministry of Economy, Trade and Industry.

I am thankful to the people of the R&D Committee of the subcontract project that spent effort in the joint research development of the VIMS evaluation system.

References

[1] International standard organization: IWA3:2005 Image safety - Reducing the incidence of undesirable biomedical effects caused by visual image sequences (2005).
[2] J. T. Reason and J. J. Brand: *Motion Sickness*, Academic Press (1975).
[3] H. Ujike, K. Ukai and K. Nihei: Survey on motion sickness-like symptoms provoked by viewing a video movie during junior high school class, *Displays*, 29, 81-89 (2008).
[4] U.S. Navy: OPNAVINST 3710.7T. (2004).
[5] H. Ujike: For the creation of a people-friendly image viewing environment, *AIST Today*, 6 (3), 28-29 (2006) (in Japanese).
[6] H. Ujike: Vol. 3 Chapter 7 Biosafety of images, *FPD Guidebook 2009 Edition*, JEITA, Tokyo (2009) (in Japanese).
[7] The Mechanical Social Systems Foundation: *"Feasibility Study for the Realization of the Visually-Induced Motion Sickness Guideline Verification System" Reported by Japan Electronics and Information Technology Industries Association* (2008) (in Japanese).
[8] H. Ujike, K. Ukai and S. Saida: Effects of motion types and image contents on visually-induced motion sickness, *Transactions of the Virtual Reality Society of Japan*, 9, 377-386 (2004) (in Japanese).
[9] H. Ujike, T. Yokoi and S. Saida: Effects of virtual body motion on visually-induced motion sickness, *Proc. IEEE EMBS 2004*, 2399-2401 (2004).
[10] H. Ujike, R. Kozawa, T. Yokoi and S. Saida: Effects of rotational components of yaw, roll and pitch on visually-induced motion sickness, *Proc. HCII 2005*, 2353-2356 (2005).
[11] H. Ujike: Effects of global motion included in video movie provoking an incident on visually induced motion sickness, *Lecture Notes in Computer Science*, 4563, 392-396 (2007).
[12] K. Jinzenji, H. Watanabe, S. Ishibashi and N. Kobayashi: Global motion estimation for static sprite production and its application to video coding, *IEICE Technical Report*, PRMU, Pattern Recognition and Media Understanding, 98 (206), 47-53 (1998) (in Japanese).
[13] H. Ujike: Estimation of visually induced motion sickness from velocity component of moving image, *Lecture Notes in Computer Science*, 5622, 136-142 (2009).
[14] N. Sugita, M. Yoshizawa, A. Tanaka, M. Abe, S. Chiba, T. Yambe and S. Nitta: Relationship between physiological indices and a subjective score in evaluating visually induced motion sickness, *Lecture Notes in Computer Science*, 5622, 114-119 (2009).
[15] H. Toyama, T. Kiryu, M. Iwaki and A. Iijima: Evaluation of visually-induced motion sickness by analysis of temporal variation in autonomic nervous activity, *IEICE Technical Report*, 109 (406), 85-89 (2010) (in Japanese).
[16] A. Iijima, K. Ukai, T. Kiryu, I. Hasegawa and T. Bando: Effect of the motion ingredient of image on cerebral blood flow, *Proceedings of the Symposium on Biological and*

Physiological Engineering, 21 (2009) (in Japanese).
[17] A. Tanaka, N. Sugita, M. Yoshizawa, M. Abe and T. Yambe: Interpolation of the subjective score of visually-induced motion sickness by using physiological parameters, *Proc. IEEE EMBS 2008*, 4595-4596 (2008).
[18] Asahi Shimbun: Guideline for eyes-friendly 3D, *Asahi Shimbun* Kanto Edition, April 10, 2010, Front Page, Morning Ed. (2010) (in Japanese).

Author

Hiroyasu UJIKE

Completed the doctorate course at the Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology in 1991. Joined the National Institute of Bioscience and Human Technology, Agency of Industrial Science and Technology in 1995. Currently, leader of the Multimodality Research Group, Human Technology Research Institute, AIST. Engages in the basic research of motion stereopsis and depth perception based on the psychophysics of vision, and works to diffuse a comfortable image environment by engaging in the R&D for image safety. As part of such activities, the VIMS evaluation system was conducted under joint development with the university and industry people. Also engages in the activities for the international standardization of image safety, such as serving as the chairman of ISO/TC 159 (Ergonomics) /SC 4 (Ergonomics of human-system interaction) /WG 12(Image safety).

Discussions with Reviewers

1 Overall composition

Comment (Hideyuki Nakashima, Future University Hakodate)

This paper describes the author's research scenario clearly. Since the core of the paper is chapter 4 where the content of the research is described, the readers may want to get to that part more quickly. Since chapter 2 is written with a strong wish to obtain the understanding of the image providers because the research is targeted toward them, the paper will be easier to read if you make this point clear with concise descriptions.

Answer (Hiroyasu Ujike)

Thank you for pointing this out. Since the result of this research is meaningless unless it is used by the image providers who are the end users, chapter 2 became rather long because I wanted to emphasize this point. I made modifications to make it as brief as possible.

2 Overall picture of the research scenario

Comment (Motoyuki Akamatsu, Human Technology Research Institute, AIST)

The goal setting of how you want the VIMS evaluation system to be used in society is stated in subchapter 2.2, and the point is clear as a *Synthesiology* paper. I think it will help if you add a diagram that shows the positioning of the developed system to clarify this goal setting for the reader. Also, as an evaluation of the result of the R&D, please describe any example where this evaluation system was used to improve some results.

Also, please write the evaluations from the users' side, like voices from the image providers that they want to try this system.

Answer (Hiroyasu Ujike)

I added Fig. 1 corresponding to the text of subchapter 2.2. For the results, I received numerous voices saying they want to try the system in the sessions where we presented the system, and I added this to the final paragraph of subchapter 2.2. The examples of actual improvements using the evaluation system are expected to occur in the future.

3 Factors of sickness

Question (Motoyuki Akamatsu)

Please state how each factor causes sickness under what conditions (such as frequency and size) for the factors shown in Table 1. Also, what is the degree of effect when compared to the global motion?

Answer (Hiroyasu Ujike)

For the conditions where the factors in Table 1 are likely to cause sickness, the degree of effect of the factors for visual global motion is not easy to answer because of the following points:

1. While the visual global motion is the factor (primary factor) that may trigger sickness due to its presence, basically, other factors are secondary factors that amplify or reduce the sickness that is occurring. The comparison is difficult since the quality of the effect on sickness is different.
2. For the secondary factors, the comparison is difficult since basically the units of parameters are different, such as the luminosity of the screen (unit: cd/m^2) and size of the field of vision (unit: deg^2).

Therefore, I shall describe the outline of the effect of major factors based on the findings we obtained and the reports available so far. Since individual difference is great for VIMS, please note the following description assumes a typical observer.

- Visual global motion: In the rotation in the three axes, it is known that the effect of roll is relatively great. However, in the rotation in one direction, the effect is largest at speed 30~70 deg/s in all rotations. In reciprocating oscillation, while there is some dependency on temporal frequency and amplitude, the speed ranges with large effects are different for each three types of rotation.
- Binocular stereopsis: The effect on sickness is shown to slightly increase by stereoscopic presentation of images and by adding depth information.
- Brightness of images: The degree of sickness is shown to decrease as the brightness of the screen decreases.
- Spatial frequency component of images: In the experiment using rotating drum with relatively simple vertical stripe pattern, it is reported that the symptoms of sickness increases by using stripe pattern with certain spatial frequency.
- Chromaticity of images: In the rotating drum experiment, it is reported that the sickness symptom increases by using colored patterns under the same brightness condition.
- Environmental illumination intensity: It is shown that the degree of sickness decreases when the environment is bright.
- Viewing distance and image size: It is shown that the degree of sickness increases as the apparent size of the image increases. However, there are reports that sickness is less likely to occur at a certain size or less (for example, 20 × 15 deg or less), and the degree of sickness is less likely to increase above a certain size (for example, 140 × 90 deg or more).
- Sensitivity to motion sickness: It is shown that VIMS is likely to occur in persons who tend to get motion sickness (or travel sickness).
- Gender and age: It is reported that women are likely to get motion sickness compared to men, and those in early teens

are relatively susceptible, and similar trends follow for VIMS.

4 Relationship to the 3D image that is in the recent news

Question (Motoyuki Akamatsu)

After the submission of this paper, 3D movies and 3D TVs became topics in the mass media, and I think the consortium in which the author was active functioned effectively to spread the importance of image safety in society. I think you should add the fact that the transition to 3D could be made because of your research result, that the human network functioned well, and that the social recognition was gained through the support of the government and others.

Answer (Hiroyasu Ujike)

Thank you very much for pointing this out. After the joint press release (April 19, 2010) by the 3D Consortium, Japan Electronics and Information Technology Industries Association, and AIST, there were many inquiries. I think, as you mentioned, it is the result of various collaborative activities by many people in the development of this evaluation system and the process of development, that there was diffusion of awareness for 3D image safety through the mass media. I added this in the latter half of chapter 6.