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# STEP TOWARD ESTABLISHING SAFETY GUIDELINES OF WEARABLE HEAD-MOUNDED DISPLAYS (HMDs)

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**Abstract:** Enormous volume of digital contents including music, video, and WWW are increasingly used in outdoor situations using several kinds of mobile devices, such as cellular phones, digital cameras, and portable music players. These devices are becoming "wearable" so that they can be used anywhere and anytime as they are used for longer time. A head mounted display (HMD) is a key device for making these devices wearable since it enables users to obtain information continuously without any extra movement of a user. Although the outdoor use of HMD is an essentially new experience for human beings and the range of its effect is not exactly known, the safety problem must be one of the most important factors for their business or daily uses. In this paper, we summarize these issues. After explaining characteristics of wearable HMD, we show existing standards related with the matter. Then we show newly arisen issues including binocular rivalry, shift of attention, and physical/physiological effects.

## 1. INTRODUCTION

Wearable computing is a new style of computing where computer devices are attached on the human body and are ready to use anytime and anywhere. This style can dramatically change our daily lives different from the conventional desktop computing style which changes the styles of business, communication, and information search/exchange [1]. Although the notion has been known for more than ten years, it has not been widely employed now. This was probably because of the lack of "killer" applications.

Recently, the situation of computer applications is changing. Enormous volume of contents including music, video, and WWW are increasingly used in outdoor situations using several kinds of mobile devices, such as cellular phones, digital cameras, and portable music players. These devices are becoming "wearable" so that they can be used anywhere and anytime as they are used for longer time. A head mounted display (HMD) is a key device for making these devices wearable since it enables users to obtain information continuously without any extra movement of a user.

Although the outdoor use of HMD is an essentially new experience for human beings and the range of its effect is not exactly known, the safety problem must be one of the most important factors for their business or daily uses. In this view point, we established a committee for discussing the matters as activities of NPO Wearable Computer Research and Development Organization (called "Team Tsukamoto"),

- in fiscal 2004, as a feasibility study of Kansai Bureau of Economy, Trade and Industry, and,
- in fiscal 2005, as a feasibility study of Ministry of Economy, Trade and Industry.

The members include academic specialties in information engineering, psychology, brain science, ophthalmology, clothing physiology, and ophthalmic optics, a lawyer, industrial engineers/managers of HMD products, devices, and services, as listed below;

- Prof. Masahiko Tsukamoto (chair, Kobe University): System and device for wearable and ubiquitous computing
- Prof. Eiji Shimizu (Takarazuka University of Art and Design): Electronic engineering, especially retina projected display
- Prof. Yuko Mizuno (University of Hyogo): Computer engineering and medial science
- Prof. Ichiro Fujita (Osaka University): Brain science, especially vision
- Prof. Kazumitsu Shinohara (Osaka University): Applied cognitive psychology
- Prof. Takashi Kawai (Waseda University): Ergonomics in advanced media
- Mr. Yoshito Fujikawa (Yodoyabashi&Yamagami LPC): Product liability law, patent
- Prof. Takashi Fujikado (Osaka University): Ophthalmology, especially visual science
- Prof. Kozo Hirata (Kobe Women's University): Home economics

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Secretariats were Dr. Tsutomu Terada (Osaka University) in fiscal 2005.

Different from indoor, immersive HMDs, wearable HMDs are characterized by their outdoor use, i.e., small and lightweight bodies, buttery operations, view field, stability against user's move, and long time use. These HMDs are categorized by some viewpoints; monocular or binocular, direct view or indirect view, see-through or occluded. Considering such variety of HMDs, we picked up and discussed several safety issues including the following;

- Sickness: due to accommodation or convergence conflicts, flicker, motion sickness, and motion after effects.
- Affects or aftereffects on eyes or brain: due to unnatural sight enforcement to eyes or brain, such as the binocular rivalry. Their exposure to electric fields is also a problematic.
- Physiological affects: User's temperature may rise due to the pressure on the head.
- Physical hazard of accident: Electric wire may be hooked on a door knob, and broken devices may damage the user and other people.
- Unexpected currents passing through human body
- Inattentiveness to potential danger: The HMD view hides a possibly large part of the outside visual field. Paying attention to the HMD may cause accident.
- Contents mismatch: Psychological affects of contents may mismatch to the circumstances.

In this paper, we summarize the discussion and show the result obtained by the discussion.
First, we make the notion of wearable HMD clear. Next, we summarize existing standards related to the matter. Then, we show some important issues arisen newly in wearable HMD. Lastly, we conclude the paper.

## 2. CHARACTERISTICS OF WEARABLE HMDs

In this section, we define the notion of wearable HMD. Fist, we explain conventional HMD, and then we describe wearable computing. At last, we show some characteristics of wearable HMDs.

### 2.1 Conventional HMDs

An HMD is a display which is mounted on the human head. This has special characteristics which are quite different from other displays such as desktop displays, mobile displays, and display which are attached with other places of the human body. Some of them are as follows;

- It must be firmly equipped on the head
- It must comfortably and safely provide a user a stable view of the screen. This is usually force whole or a part of the device to be placed in front of user's eyeball.

So far, there have been many types HMD developed and sold. Typical products are categorized as the following two types;

- Binocular, full-face HMDs for mainly enjoying audio/visual contents. Most of them are immersive, i.e., shutting out the outside view for a user to concentrate enjoying the contents. In these HMDs, wide view angle and high resolution are important.
- Stereoscopic HMDs for three dimensional virtual reality applications. In these HMDs, different images are provided for right eye and left eye respectively. Similar to the previous case, most products are immersive.

Note that these HMDs have not been established a large market in these ten years and many makers withdrew from the market.

### 2.2 Wearable Computing

Wearable computing is a new style of computing where a user equips computer devices on his/her body as if it were clothes. It makes it possible to use computers while he/she is doing something in the real world. Typically, a user equips a head mounted display (HMD) on the head and a PC on the waist or other places on the body. In this way, a user can use a computer anytime and anywhere including the situation in which a user cannot use a computer so far, such as on walking, and on a train.

There are wide varieties in the usage of wearable computing. In US, wearable computing has been employed in military use for more than 30 years. Industrial use is also a promising application of wearable computing. All people except for those working at a desk have a potential to employ wearable computing. Further, the daily use is other promising and interesting direction of wearable computing [1].

In the technical point of view, wearable computing becomes popular in the near future because of the following reasons;

- There are a lot of mobile IT products that has already been popular and widely used such as digital cameras, digital video cameras, portable games, portable audio players, and cellular phones. Many people use such devices in outdoor situations. They usually bring them in their pockets and take out from the pocket when they use them. If they are used more often, they will naturally employ wearable styles which are more convenient for the user. We consider wearable cellular phones, wearable digital cameras, and wearable audio players are promising directions of wearable computing in the near future.
- Communication infrastructure has been fully expanded. People are using many types of communication services such as the Internet service, full-time packet connection services, and location services for cellular phone. They will become a good infrastructure for wearable computing to obtain/exchange information with other wearable computers, ubiquitous computers, and remote servers.
- Sensor devices were changed dramatically in recent few days. Not only gyro-sensors, magnetic sensors, and GPS (Global Positioning Systems) but also IC tags are recently paid much attention, and many services/businesses are now developed. To obtain and observe such information anytime and anywhere will become one of the most important functions of wearable computing.
- National policy of Japan or corporate strategies of many Japanese electronic companies include the development of wearable and ubiquitous computing. There are a lot of seminars held and books published on wearable and ubiquitous computing.

Relating with the last two reasons, we can say that HMD will play an important role as a ubiquitous information viewer.

### 2.3 Wearable HMDs

We use the word “wearable HMD” as HMD for wearable computing. A wearable HMD has the following characteristics which are different from the conventional HMDs described in subsection 2.1;

- It must be driven by butteries: In order to use it in outdoor situations, HMD should be driven by butteries. If it is used “always”, it must be able to run more than half day.
- It must be non-immersive: Wearable HMD is often used in outdoor situations, or with doing some other jobs. Therefore, the outside view must be widely kept for a user to observe or interact with his/her environment. Monocular HMD is a solution for keeping outside view. A binocular HMD is also possible if it is enough slim or if it is see-through.
- It must not disturb user’s movement: A user must be able to move with wearing HMD. Thus, HMD should be fixed firmly, and its cable should not be an obstacle in user’s move. Note that electric wire is often hooked on a door knob in practical use.
- It must be suitable for long duration equipment: This point is important because some applications may force users to equip HMDs as long as a whole day. However, even if in this case, the substantial use time may be very short. The HMD screen is often used for an auxiliary purpose, and the user mainly focuses on real world objects, which results in the substantial short time use of HMD. In this sense, comfortability of equipment is rather important than visual aspects.

Based on these requirements, a lot of HMDs are developed and on sale. These HMDs can be classified in several points of view as follows;

- Monocular vs. binocular. In general, a binocular HMD is good in watching the screen, but becomes an obstacle in getting the outside view. On doing other works, a monocular HMD has an advantage.
- Direct view vs. indirect view. Direct view means the method to obtain a view by the normal use of crystalline lens. Indirect view means abnormal uses of them such as by a retina scanning, or by a retina projection.
- Fix methods of a display. There are many ways of fixing a display in front of user’s eyeball, such as the headband-style, the headphone-style, the glasses-style, and the cap-style. The style of contact lens may be realized in the future.
- See-through vs. non-see-through. A see-through HMD is good in obtaining the outside view. It is also suitable to augmented reality applications. A non-see-through HMD becomes smaller in general.
- The range of visual fields, brightness, and focus distance are different in each product.

Uses of these HMDs are not exclusive, i.e., we may wear multiple HMDs in the future. By using multiple HMDs, we can obtain a lot of information at a time. For example, some people may watch TV while time watch and calendar are shown on other screens. Other people may enjoy a sports program while reading E-mail. On considering such cases, the following points should be taken into account in designing a future HMD;

- The display part of HMD must be small enough to allow other HMDs to be placed at other locations in front of user’s eyeball.
- The display part of HMD must have flexibility in fixing its location.

## 3. RELATED STANDARDS

Concerning safety problems of wearable HMD, there are many related standards and guidelines. Table 1 shows the search result in Japan Standard Association (JSA) Web Store (www.webstore.jsa.or.jp). The table shows the number of standards registered at the database. The search was done in Japanese and in this table corresponding English words are listed, whose meanings are slightly different form the original Japanese words.

Table 1. Search result of related standards in JSA Web Store (www.webstore.jsa.or.jp)

| Keywords | Hit count |
|---|---|
| safety | 714 |
| vision | 296 |
| eye | 135 |
| display | 7 |
| glasses | 8 |
| attention | 8 |
| human body | 42 |
| body | 16 |
| clothes | 23 |
| clothing | 24 |
| equipment | 16 |
| cellular phone | 3 |
| earphone | 10 |
| car navigation system | 1 |
| lower-limb prosthesis | 13 |
| arm prosthesis (artificial han | 2 |
| pace maker | 6 |
| headphone | 1 |
| contact lens | 37 |
| helmet | 2 |
| binocular | 7 |
| telescope | 21 |
| microscope | 96 |
| camera | 69 |

As described in subsection 2.1, an HMD itself is not new one, and there are several guidelines for conventional types of HMDs, i.e., AV HMD and VR HMD. From these guidelines, many important points can be extracted. For example, sickness occurs due to accommodation or convergence conflicts, flicker, motion sickness, and motion after effects, and the specific parameters are given in order to prevent users from getting such sickness caused by the HMD use.

Concerning an electromagnetic wave, a number of standards and guidelines are published and a lot of researches have been done especially for cellular phone. Since a wearable HMD is used on the top of the human head, an electromagnetic inspection is needed.

As for unexpected current passing through human body, there exist several standards. The situation is similar to pace makers, healthcare devices such as low-frequency therapy devices, electronic upper/lower limb prosthesis, hearing-aids.

A danger on stumble or accident, the enough strength of whole body of HMD is needed. This is similar to headphone and glasses. For example, several methods are defined for experiments on measurement of the strength of a glasses frame.

Further, in order to prevent accidents in using an HMD, the enough eyesight view must be kept. There are several standards for safe eyesight view in doing some jobs such as for operators.

## 4. NEW ISSUES

The issues which are not appeared in previous standards or guidelines are discussed in this section.

### 4.1 Affects or after effects on eyes or brain

A wearable HMD sometimes forces user unnatural sight enforcement to eyes or brain, such as the binocular rivalry. Therefore we must take care of affects or aftereffects on eyes or brain. In this sense, designing HMD needs to determine the following parameters;

- The difference between the brightness of the screen and the surroundings
- The location and the size of the screen in front of the user's sight.

Since these points depend on usages and situations, we must imagine several concrete scenarios to discuss further on the matter.

As mentioned earlier, monocular HMD forces a user to watch screen with single eye. This may cause binocular rivalry, which has been examined for these several years in the brain science area. The relationship between binocular rivalry and use of monocular HMD must be clarified in the future. It should be carefully examined how long a user can use the HMD and how HMD affects small children, especially considering the relationship with strabismus or binocular dysfunction. We should note that there have been similar monocular devices such as camera, microscope, telescope, and visual acuity testing equipment. Since there are few claims on safety of these devices, we may be optimistic on this issue but we must check the difference to them.

A retina-scanning display uses a laser beam directly put on the retina, which seems very dangerous. We must carefully design it considering the laser strength, the upper limit of continuous use, and the avoidance of dangerous malfunction.

### 4.2 Inattentiveness to potential danger

There seems no JIS, ISO standard on inattentiveness to potential danger caused by paying attention to electronic devices. Since the HMD view hides a possibly large part of the outside visual field, paying attention to the HMD may cause accident. This is sometimes called shift of attention. Similar problems are the followings;

- Use of a cellular phone. Both of cellular phone and wearable HMD can be used in outdoor situations, i.e., on walking, on doing jobs, on a train, and so on. Recent usages of cellular phone include more and more visual information such as E-mail and Web, and not only audio but also visual information will be considered in this problem of shift of attention in using cellular phone. The guidelines for cellular phone on this matter are helpful in our case.
- Use of a car navigation system. It provides a lot of visual information under a circumstance where an accident may easily occur if a driver does not pay attention to driving a car. As a result, the safety problem becomes very serious. The situation is similar to the wearable HMD case if it is used in dangerous situations.

In the case of wearable HMD, since dangerous factors changes according to its usage, we must classify use cases such as in driving, in riding a bicycle, on walking, on a train, in engaging dangerous tasks. In most cases, sudden occurrence of sound or emission of strong light are dangerous and may cause an accident if a user is in a dangerous situation. Very concise contents on HMD may cause an accident since it forces the user to pay more attention to the contents.

### 4.3 Distress by equipment

Some HMDs may pinch user's head. For avoiding this, an HMD should be designed based on human body models or some results of ergonomics. There are many standards of this. Further, we can refer to standards for conventional equipments on the body, such as hats, glasses, headphones, headbands, and combs. They often include weight, their material, and the location of equipment, but sometimes it is different from the HMD case. As mentioned in subsection 2.1, VR HMDs are similar to our case, but wearable HMD is different from in the situation; it is used in an outdoor situation, and has stronger requirements on weight and comfortable set.

Cables are often used with HMD in order to connect the display part with a video converter or video resources, which usually becomes a strong constraint of a user's movement. It may become obstacle if it is too long, and it constraints the movement of user's head if it is too short. This point is similar to cases of earphone, headset of portable music players, and earphone-microphone of cellular phones, but the HMD case is more serious because a cable becomes thicker in order to transmit visual information.

### 4.4 Visibility

Visible contrast and visible size of characters are important on providing contents in HMD. Such visibility also affects on shift of attention and distress by equipment described above. The problem is similar to the cases of Web accessibility and universal design, for which there are many documents. These documents sometimes concretely show numerical criteria concerning the matter, however, the vision mechanisms are different in the case of wearable HMD, and therefore we must consider how these documents can be applied to our case. We must examine our case especially taking care of the following points;

- Difference on visibility caused by structure of HMD
- Difference on visibility caused by environment
- Difference on visibility caused by individuals, i.e., personal equation

### 4.5 Physiological and psychological effects of contents

Although several reports were published concerning the matter, they mainly focused on indoor use of TV or internet contents, while we expect outdoor in our case. Further, the screen of HMD cannot be seen by other people. If we remind that the HMD content strongly affects the user's state of mind, surrounding people may be anxious about the user's psychological mismatching.

Thus, we should discuss the following matters;

- Which contents is appropriate / inappropriate in a given situation?
- Is it necessary to show other people indication of contents? Movie Ratings, V-chips are based on the same objectives. We may define similar indication methods.

Further, as a physiological affects, user's temperature may rise due to the pressure on the head.

### 4.6 Other Issues

Danger on tumble or accident is in some part similar to headphone or glasses, however, there are few description on head equipment. As described in subsection 2.4, methods for fixing display on the head widely vary and such a physical safety matter quite changes according to the method. We must examine more closely on the matter.

## 5. CONCLUSION

In this paper, we pointed that many elements concerning safety matters changes according to the use case and the situation. Thus the next step must include case studies in which use cases are concretely determined. In fiscal 2006, we will again have a committee for this purpose. It will be also a feasibility study of METI, especially focusing on wearable cellular phone, wearable digital camera, and wearable video player. We aim at establishing guidelines in the future.

We must put a lot of assumptions on HMD mechanisms, usage, and environment, since wearable HMDs are not popular now. However, since it will have a large impact on society in the future, we must discuss on every issues that are considered to be important now. A similar case is a consumer robot. It does not have a popular market now but it needs a safety guideline since it will have a large impact on society. A consortium is now discussing the matter.

## 6. REFERENCES

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