QoE Assessment in Olfactory and Haptic Media Transmission: Influence of Inter-Stream Synchronization Error

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***Abstract*—In this paper, we deal with harvesting fruit in a 3-D virtual space for an olfactory and haptic media display system. Making use of the system, a user can pick fruit from a tree in the 3-D virtual space and perceive the smell of picked fruit by using an olfactory display (SyP@D2) and the reaction force when picking fruit by using a haptic interface device (PHANToM Omni). In the case where there exists inter-stream synchronization error between olfactory and haptic media, we assess the inter-stream synchronization quality as the quality of experience (QoE).**

I. Introduction

Multi-sensory communications have been emerging. Vision and auditory sensation are mainly used as computer interfaces at the present time. In multi-sensory communications, we treat other senses such as olfaction, tactile sensation, and gustation as computer interfaces [1]. We can share not only vision and auditory sensation but also olfaction [2], tactile sensation [3], and gustation [4] through a network in order to communicate naturally and realistically. This paper focuses on transmission of vision, tactile sensation, and olfaction.

However, when we transmit visual, haptic, and olfactory media streams over the Internet, the network delay jitter disturbs the temporal relationships among the media streams. Thus, the quality of service (QoS) of the streams may seriously be degraded. To solve this problem, we need to carry out media synchronization control [5]. Mainly, there are two types of media synchronization control. One is intra-stream synchronization control, and the other is inter-stream synchronization control [6]. It is necessary to clarify the influence of inter-stream synchronization error on the quality of experience (QoE) [7] for efficient media synchronization control.

QoE in haptic media and video transmission has been assessed so far [8], [9]. Kameyama and Ishibashi [8] measured the allowable range and imperceptible range of inter-stream synchronization error between haptic media and video by conducting an experiment in which the haptic media and the video of a real object which a user is touching are transmitted to another user. Fujimoto *et al.* [9] investigated the influences of inter-stream synchronization error between haptic media and video on the inter-stream synchronization quality and the easiness of the collaborative work in which two users lift and move a real object by holding the object between the styli of the two haptic interface devices.

There is a few papers handling olfactory media together with other media [10], [11]. Ademoye *et al.* [10] investigated the influence of inter-stream synchronization error between olfactory media and video on the inter-stream synchronization quality. They concluded that when the inter-stream synchronization error is between about -20 seconds and around +30 seconds, the inter-stream synchronization error is hardly perceived (if the synchronization error is negative, the olfactory media are output ahead of the video). Also, Kadowaki *et al.* [11] investigated how to transmit and present olfactory information together with audio-visual information. They tried to solve a problem of asynchrony between olfactory and audio-visual media which causes various problems such as lingering of odors and human olfactory adaptation in the air by using an olfactory display which can eject a pulse of the smell for a very short period of time.

However, no one has investigated the influence of inter-stream synchronization error between olfactory and haptic media on QoE. Since QoE deteriorates owing to the inter-stream synchronization error, it is necessary to clarify the influence of inter-stream synchronization error between olfactory and haptic media on QoE.

In this paper, we deal with a system which displays olfactory and haptic media. Making use of the system, a user can pick fruit from a tree in a 3-D virtual space and perceive the smell of picked fruit and the reaction force when picking fruit. The system is referred to as the *olfactory and haptic media display system* in this paper. By QoE assessment, we investigate the influence of inter-stream synchronization error between olfactory and haptic media.

The rest of this paper is organized as follows. We explain the olfactory and haptic media display system in Section II. Section III describes the assessment method, and assessment results are presented in Section IV. Section V concludes the paper.

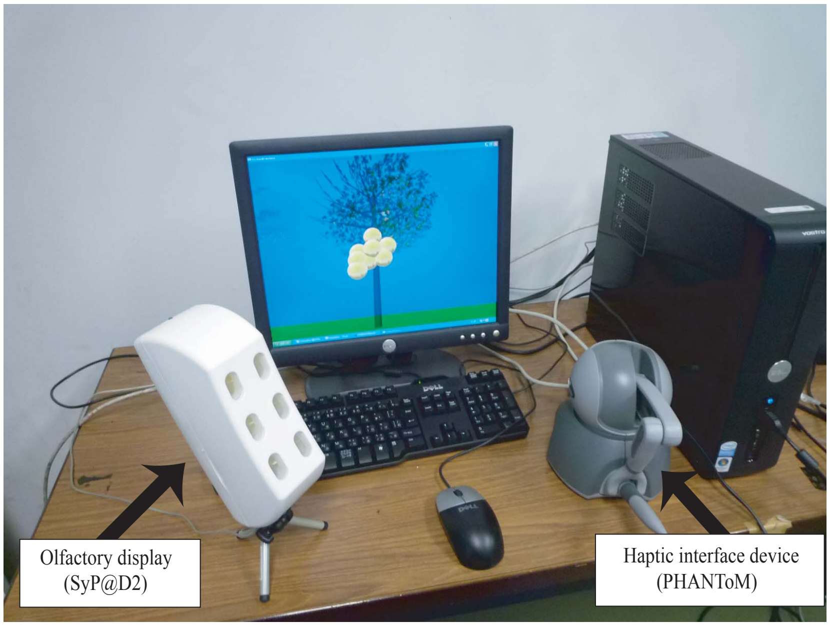

Fig. 1. Configuration of olfactory and haptic media display system.

II. Olfactory and Haptic Media Display System

As shown in Fig. 1, the olfactory and haptic media display system consists of the PHANToM Omni [12] (just called PHANToM here) as a haptic interface device, the SyP@D2 [13] as an olfactory display, and a personal computer (PC). In this paper, for simplicity, a stand-alone system is used to investigate the influence of inter-stream synchronization error between olfactory and haptic media. We use the PHANToM to touch and catch an object in a 3-D virtual space. The reaction force is calculated by using the spring-damper model [14]. PC inputs the positional information of the cursor (i.e., a position which a user tries to touch or is touching with his/her PHANToM) and performs collision detection between the cursor and an object. The reaction force $\boldsymbol{F}$ is calculated by the following equation.

$$\boldsymbol{F} = K_{\mathrm{s}} \cdot \boldsymbol{x} + K_{\mathrm{d}} \cdot \boldsymbol{v},$$

where $\boldsymbol{x}$ is a vector representing the depth of penetration of the PHANToM cursor into the surface of the object, $\boldsymbol{v}$ is the velocity of the PHANToM cursor relative to the object, K_{s} is the spring coefficient, and K_{d} is the damper coefficient.

The SyP@D2 displays a smell to a user by blowing air into a smell cartridge attached to the main body. We can attach six cartridges to the SyP@D2, and the SyP@D2 can diffuse each smell at any time. There are some parameters of the SyP@D2 which we can set up, such as the name of smell, the duration of diffusion, and the intensity of diffusion (i.e., the power of wind). In this paper, we set the distance between a user and the SyP@D2 to about 0.3 m. We measured the average time that it takes for the user to perceive the smell. As a result, when we set the intensity of diffusion to the maximum, it took about 2 seconds for the user to perceive the smell. Therefore, the maximum wind speed of the SyP@D2 is approximately 0.15 m/s.

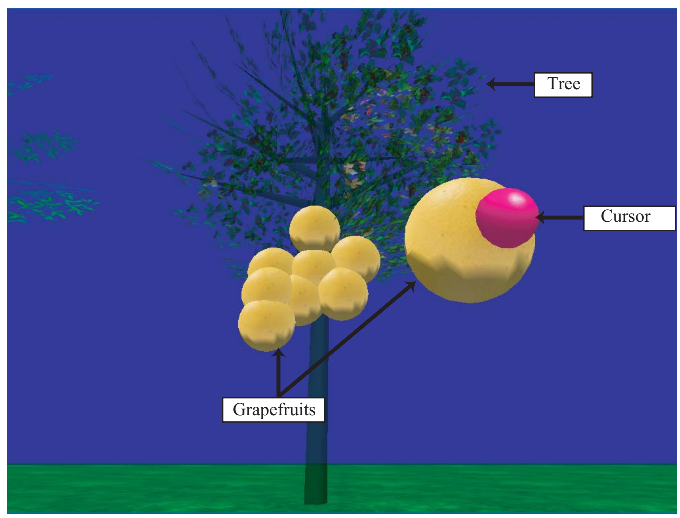

Fig. 2. Displayed image after picking grapefruit.

In this system, a user can move the viewpoint in a 3-D virtual space by keyboard input. There is a grapefruit tree in the virtual space. The user can touch a grapefruit by manipulating the PHANToM and catch the grapefruit by pressing the button of the PHANToM stylus while touching the grapefruit. Also, he/she can pick a grapefruit from the tree by pulling the grapefruit while catching it. We show a displayed image after picking a grapefruit in Fig. 2. When he/she pulls a grapefruit, the reaction force is generated. If the reaction force exceeds a threshold value (2.45 N), the grapefruit pulled by him/her is picked. Before exceeding the threshold value, the strength of the reaction force is the same as that of the force given by him/her; however, the direction is opposite. After exceeding the threshold value, the reaction force $\boldsymbol{F}$ is calculated by the following equation.

$$\boldsymbol{F} = \boldsymbol{F}_{\mathrm{c}} + C_{\mathrm{d}} \cdot \boldsymbol{d},$$

where $\boldsymbol{d}$ is a vector representing the movement of a picked grapefruit, $\boldsymbol{F}_{\mathrm{c}}$ is the current reaction force, and C_{d} is a dynamic coefficient to express feel of picking a grapefruit. In addition, the smell of a grapefruit is diffused by the SyP@D2 when the grapefruit is picked. If he/she releases the button of the PHANToM stylus after picking the grapefruit, the grapefruit disappears and the diffusion of the smell stops.

Figure 3 shows functions of the olfactory and haptic media display system. PC inputs the information about the stylus button (ON or OFF) and the positional information of the cursor every millisecond. By using these types of information, we update the information of the reaction force, the olfactory information, and the positional information of grapefruit, where the olfactory information means the name of smell, the duration of diffusion, and the intensity of diffusion; also, the positional information of grapefruit has an effect on the visual media. The information of the reaction force, the olfactory information, and the positional information of grapefruit are output after buffering for a certain period of time which is set beforehand. In this paper, for simplicity, the haptic media are assumed to be synchronized with the visual media. Therefore, the buffering time of the information of the reaction force is set to the same value as that of the positional information of grapefruit in our assessment[1].

We need to generate the difference in output time between olfactory and haptic media to investigate the influence of inter-stream synchronization error between the two media on QoE. In this paper, we set the buffering time of the haptic media to 0 ms, and generate the temporal difference by outputting the olfactory media earlier or later than the haptic media. When outputting the olfactory media later, as described earlier, we generate a delay by buffering. When outputting the olfactory media earlier, we do not use buffering, and we output the olfactory media when the force given by a user exceeds a threshold value. Then, since the inter-stream synchronization error between olfactory and haptic media is not constant, we calculate the average of the inter-stream synchronization error generated in QoE assessment. Thus, we change the inter-stream synchronization error between olfactory and haptic media by adjusting the output time of the olfactory media.

III. Assessment Method

In QoE assessment, each subject operates the PHANToM and picks grapefruits in the virtual space. Before carrying out the QoE assessment, we make each subject pick some grapefruits without the inter-stream synchronization error in order to get the subject used to picking. Then, the subject picks grapefruits with the inter-stream synchronization error. As described earlier, we generate the inter-stream synchronization error by outputting the olfactory media earlier or later than the haptic media. If the inter-stream synchronization error is positive, the haptic media are output ahead of the olfactory media. In this case, the error between olfactory and haptic media is changed from 0 ms to +3000 ms. Then, the constant additional delay of the olfactory media is changed from 0 ms to +1000 ms at intervals of 100 ms, and is changed from +1000 ms to +3000 ms at intervals of 500 ms. When the olfactory media are output ahead of the haptic media (the inter-stream synchronization error is negative), as described earlier, the inter-stream synchronization error is not constant. Therefore, we change the threshold value of the force when outputting the olfactory media from 0 N to 2.10 N at intervals of 0.35 N in order to change the average of the inter-stream synchronization error (the average time from outputting the olfactory media to picking a grapefruit). When the threshold value of force is 0 N, the olfactory media are output on catching a grapefruit even if a user has not picked the grapefruit. The average of the inter-stream synchronization error will be shown in Section IV.

TABLE I
Five-grade quality of scale.

Score	Description
5	Excellent
4	good
3	fair
2	poor
1	bad

Each subject is asked to base his/her judgement about the inter-stream synchronization quality in terms of wording used to define the subjective scale, as shown in Table I. The subject gives a score from 1 through 5 to each test to obtain the *mean opinion score* (*MOS*) [15], which is one of QoE parameters. We set the diffusion intensity of the SyP@D2 to the maximum in our assessment. Each subject picks grapefruits while listening to classical music (Four Seasons by Vivaldi) to prevent the subject from being influenced by the sound of blowing from the SyP@D2. In addition, the subject takes a 30-second rest every judgement to prevent him/her from being influenced by lingering odors in the air and human olfactory adaptation (we verified that there is no influence of lingering smell in the air and human olfactory adaptation if each subject takes a 30-second rest in a preliminary experiment). The subjects were men and women whose ages were between 21 and 30. It took about half an hour per subject to complete all the judgments.

IV. Assessment Results

We show the MOS value of the inter-stream synchronization quality as a function of the inter-stream synchronization error in Fig. 4, where the 95 % confidence intervals are also plotted. In Fig. 4, when the inter-stream synchronization error

[1]We assessed the influence of inter-stream synchronization error between visual and haptic media on QoE. As a result, we saw that inter-stream synchronization errors between about 0 ms and around +40 ms are imperceptible (if the synchronization error is positive, the haptic media are output ahead of the visual media). We will report the assessment results in another paper.

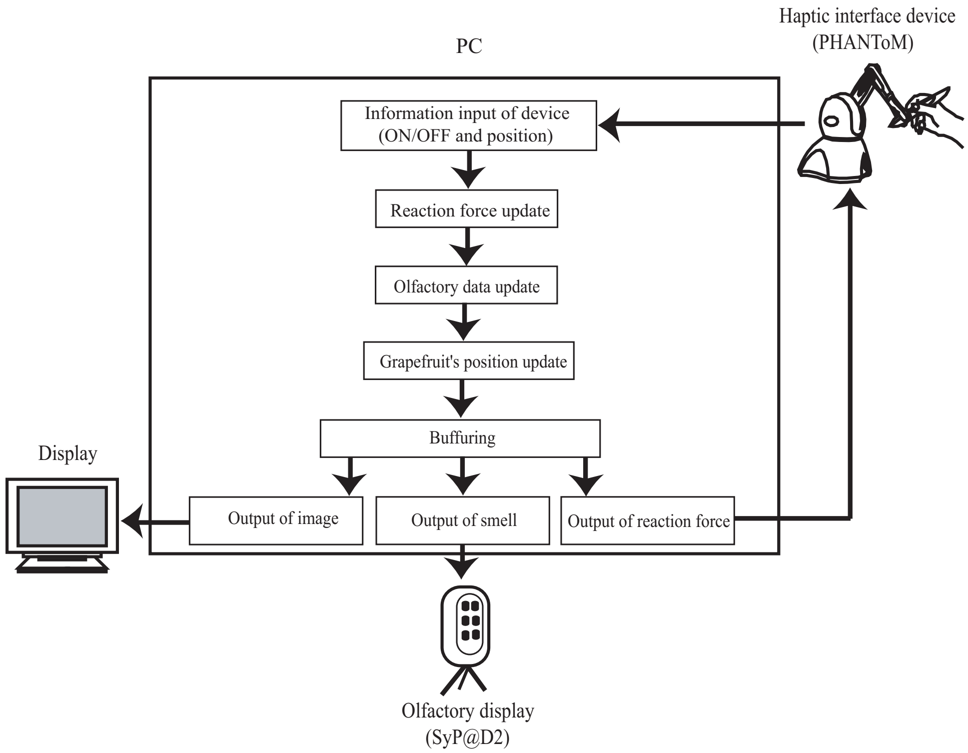

Fig. 3. Functions of olfactory and haptic media display system.

TABLE II
AVERAGE AND COEFFICIENT OF VARIATION OF INTER-STREAM SYNCHRONIZATION ERROR (WHEN OLFACTORY MEDIA ARE OUTPUT AHEAD OF HAPTIC MEDIA).

Threshold value of force [N]	0	0.35	0.70	1.05	1.40	1.75	2.10
Average of inter-stream synchronization error [ms]	−1379.13	−934.73	−954.89	−630.59	−669.98	−249.42	−89.84
Coefficient of variation of inter-stream synchronization error	0.57	0.96	0.97	0.72	1.08	1.08	0.93

is positive, the horizontal axis means the constant delay of the olfactory media. When the inter-stream synchronization error is negative, the horizontal axis denotes the average of the inter-stream synchronization error. We show the average and coefficient of variation of the inter-stream synchronization error in Table II. From Table II, we find that the average of the inter-stream synchronization error is between about −1380 ms and around −90 ms. In addition, as the threshold value of the force becomes larger, the average of the inter-stream synchronization error increases. Moreover, the coefficient of variation is between about 0.57 and around 1.08.

In Fig. 4, for inter-stream synchronization errors between about −1380 ms and around −250 ms, the MOS value of the inter-stream synchronization quality is larger than 4 (good). As described earlier, since it takes approximately 2 seconds to perceive the smell, we see that the subjects hardly perceive the inter-stream synchronization error when it takes from about 620 ms to around 1750 ms to perceive the smell after picking a grapefruit. In addition, Figure 4 reveals that for inter-stream synchronization errors between about −1380 ms and around +400 ms, the MOS value of the inter-stream synchronization quality is larger than 3 (fair); this means that the inter-stream synchronization error is allowable. The allowable range in this paper is smaller than that in [10]. This is because subjects are more sensitive to the inter-stream synchronization error in the case where the olfactory and haptic media are perceived together than in the case where the olfactory media and video are perceived together.

In this paper, however, we cannot assess the inter-stream synchronization quality when the inter-stream synchronization error is smaller than about −1380 ms. The reason is as follows. In our system, it takes about 1380 ms for a user to pick a grapefruit. When the olfactory media are output ahead of the haptic media, we cannot generate inter-stream synchronization errors larger than about 1380 ms. To assess the inter-stream synchronization quality when the inter-stream synchronization error is smaller than about −1380 ms, we have just implemented a new function in our system. In the new function, if the reaction force which is generated when a user pulls a grapefruit continues to exceed a threshold value for 1 second, the grapefruit pulled by him/her is picked; thus, it takes more than about 1380 ms for a user to pick a grapefruit. There is a possibility that a user feels uncomfortable when it takes a long time to pick a grapefruit. For this reason, we also

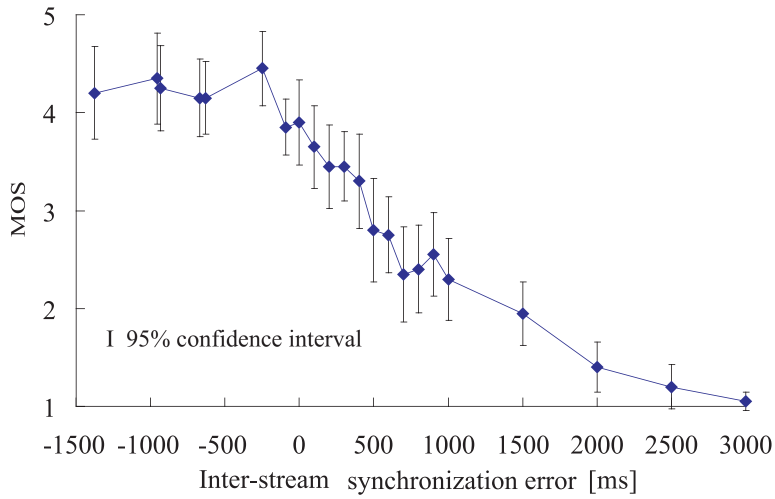

Fig. 4. MOS of inter-stream synchronization quality.

investigate which method is felt more real, the conventional one or the new one. Currently, we are carrying out the two types of assessment. We will report the assessment results in the camera-ready version of this paper.

V. Conclusions

In this paper, we investigated the influence of inter-stream synchronization error between olfactory and haptic media on QoE. As a result, we found that for inter-stream synchronization errors between about -1380 ms and around -250 ms, the inter-stream synchronization quality is good. In addition, we saw that inter-stream synchronization errors between about -1380 ms and around +400 ms are allowable.

As the next step of our research, we will investigate the influences of packet loss and network delay jitter on QoE. Also, we will study media synchronization control which takes advantage of the results obtained in this paper for olfactory and haptic media.

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References

[1] K. Hirota and M. Hirose, "Toward multi-sensory communication: Transmitting the sense of touch and smell," (in Japanese), *IPSJ Technical Report*, vol. 2002, no. 38, pp. 13–18, May 2002.
[2] T. Nakamoto, M. Nimsuk, B. Wyszynski, H. Takushima, M. Kinoshita, and N. Cho, "Experiment on teleolfaction using odor sensing system and olfactory display synchronous with visual information," *Proc. International Conference on Artificial Reality and Telexistence (ICAT'08)*, pp. 85–92, December 2008.
[3] M. A. Srinivasan and C. Basdogan, "Haptics in virtual environments: Taxonomy, research status, and challenges," *Computers and Graphics*, vol. 21, no. 4, pp. 393–404, April 1997.
[4] T. Narumi, T. Futamata, K. Nishimura, T. Tanikawa, and M. Hirose, "A basic study on gustatory display with visual feedback," (in Japanese), *ITE Technical Report*, vol. 33, no. 21, pp. 107–112, June 2009.
[5] G. Blakowski and R. Steinmetz, "A media synchronization survey: Reference model, specification, and case studies," *IEEE J. Sel. Areas Commun.*, vol. 14, no. 1, pp. 5–35, January 1996.
[6] Y. Ishibashi and S. Tasaka, "A comparative survey of synchronization algorithms for continuous media in network environments," *Proc. the 25th Annual IEEE Conference on Local Computer Networks (IEEE LCN'00)*, pp. 337–348, November 2000.
[7] ITU-T Rec. G.100/P.10 Amendment 1, "New appendix I - Definition of quality of experience (QoE)," International Telecommunication Union, January 2007.
[8] S. Kameyama and Y. Ishibashi, "Perception of synchronization errors in haptic and visual communications," *Proc. SPIE Optics East, Multimedia Systems and Applications IX*, vol. 6391, no. 7, October 2006.
[9] T. Fujimoto, Y. Ishibashi, and S. Sugawara, "Influences of inter-stream synchronization error on collaborative work in haptic and visual environments," *Proc. the 16th Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems (Haptics'08)*, pp. 113–119, March 2008.
[10] O. A. Ademoye and G. Ghinea, "Perceived synchronization of olfactory multimedia," *IEEE Transactions on Multimedia*, vol. 11, no. 3, pp. 561–565, April 2009.
[11] A. Kadowaki, D. Noguchi, S. Sugimoto, Y. Bannai, and K. Okada "Development of a high-performance olfactory display and measurement of olfactory characteristics for pulse ejections," *Proc. 10th Annual International Symposium on Applications and the Internet (SAINT'10)*, pp. 1–6, July 2010.
[12] J. K. Salisbury and M. A. Srinivasan, "Phantom-based haptic interaction with virtual objects," *IEEE Computer Graphics and Applications*, vol. 17, no. 5, pp. 6–10, September/October 1997.
[13] Exhalia., http://www.exhalia.com/.
[14] SensAble Technologies Inc., "3D Touch SDK OpenHaptics Toolkit programmer's guide version 1.0," 2004.
[15] ITU-R BT. 500-11, "Methodology for the subjective assessment of the quality of television pictures," 2002.