Experiment on Teleolfaction Using Odor Sensing System and Olfactory Display Synchronous with Visual Information

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Abstract

We propose a teleolfaction system synchronous with visual information. The system is made up of an odor sensing system and a remotely placed olfactory display, and both of them are connected via Internet. In addition to the olfactory system, a web camera captures image around the sniffing point and that image appears at the computer display connected to the olfactory display at remote site. The questionnaire survey at the exhibition revealed that a user can enjoy smell together with movie in real time even if he/she stays at the remote site

1. Introduction

A human perceives sensory information such as vision, audition, gustation, olfaction and taction. Although visual and auditory information can be electronically utilized, the methods to present other sensory information and transmit that information to a remote site are not common. We focus on olfactory information since it drastically enhances the sense of presence when an object related to smell is presented [1-2].

The equipment called an olfactometer has been used for many years to give a human an olfactory stimulus in order to investigate the human perception about smells or measure EEG (Electroencephalogram) induced by olfactory stimuli [3] However, its size is large and expensive.

Recently several researches on olfactory display were reported. PC-controlled scent diffuser was proposed [4-5]. An animation with smells can provide much sensation to users [6]. Moreover, the interactive cooking game was realized using the olfactory display [7]. Other researchers proposed a spot scent using an air cannon [8] and wearable olfactory display [9]. The olfactory display for blending up to 32 odor components to create a variety of smells was also developed [10]. Although smell likely to match the scene is selected in the animation, it is not based on actual smell. Moreover, the concentration sequence of the smell was manually created without recording.

An odor sensing system can be used to collect the actual smell information. The odor sensing system consists of an array of sensors with partially overlapping specificities and the pattern recognition technique [11]. This technology has been studied in a sensor field for approximately two decades. However, it has been studied independently of an olfactory display.

Thus, the concurrent recording and reproduction of smell synchronous with movie was previously reported [12]. Although the smell reproduction together with movie was successfully performed, it was not possible to reproduce it in real time at remote site.

In this paper, we propose a teleolfaction system using an odor sensing system and an olfactory display. Users can sniff the smell in real time even if the odor source is located far away from users. They can also smell simultaneously with watching a video, transferred from the recording system via the Internet. Thus, users can perceive much sensation of reality of the object even at the remote site. This effect is called the teleexistence of the olfaction. The proposed system was demonstrated at the exhibition and its fundamental capability was confirmed by the result of the questionnaire survey.

2. 2. System structure

The concept of teleolfaction system with vision is illustrated in Figure 1 (a). An object is captured by recording system and its image and scent information is transmitted to the display system located away from the object. The display system reproduces the object in vision and olfaction. The actual diagram of teleolfaction system is depicted in Figure 1 (b). It consists of recording system and olfactory display system.

2.1. Recording system

The recording system records odor information and movie, and transmit them to the display system. The system consists of an odor sensing system, a web camera and a laptop computer.

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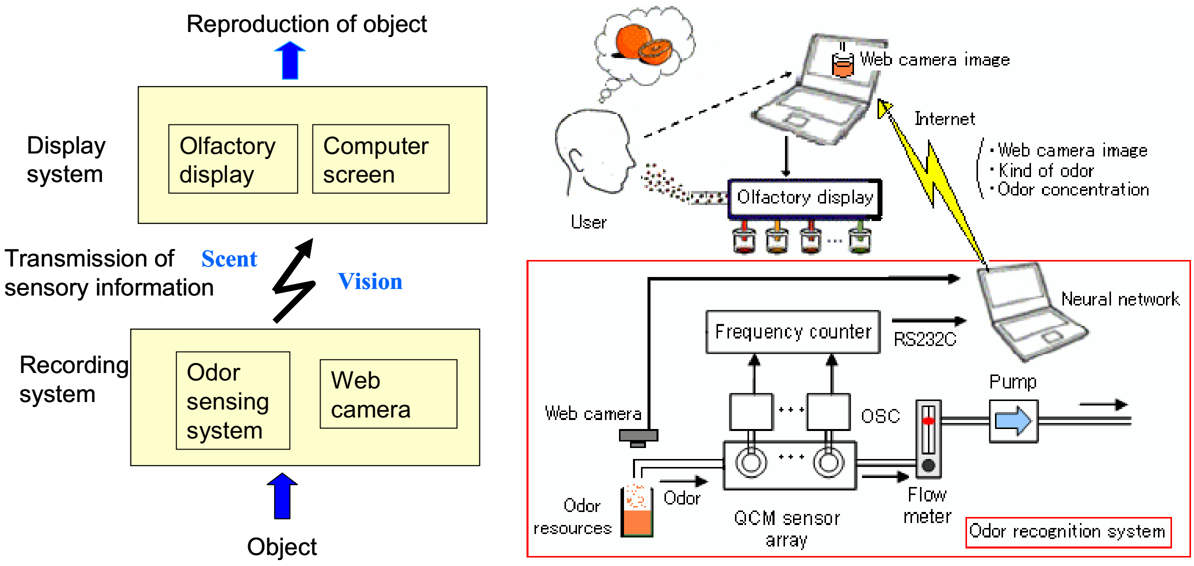

(a) (b)

Figure1: System structure (a) Concept and (b) structure.

Ambient air is sucked into the sensor cell through Teflon tube using an air pump (Iwaki, APN-215NV-1) at the flow rate of 600ml/min. In the sensor cell, four QCM (Quartz Crystal Microbalance) gas sensors (AT-CUT, 20MHz) were placed. The photo of sensor cell and the peripheral circuits are shown in Figure 2. QCM gas sensors work based upon mass loading effect where adsorbed mass of the vapor changes the resonance frequency [13-14]. Those sensors are often used in odor sensing system. The QCM sensors were coated with sensing films such as Apiezon L, polyethylene glycol 1000 (PEG1k), silicone OV-17 (OV-17) and trecresyl phosphate (TCP). Those sensing film are stationary phase materials for gas chromatography.

The coating technique is important to obtain the reproducible sensor characteristics. The ultrasonic atomizer was used for sensing film coating although simple airbrush was insufficient for obtaining the stable result [15-16].

The QCM sensors are connected to oscillator circuits and the changes of oscillation frequencies are measured by a multi-channel frequency counter implemented into a FPGA(Field Programmable Gate Array). The circuit was made using VHDL. Each channel of the frequency counter is a binary modulus counter with its sampling interval of 1s. The measured data are sent to the computer every second via RS232C interface.

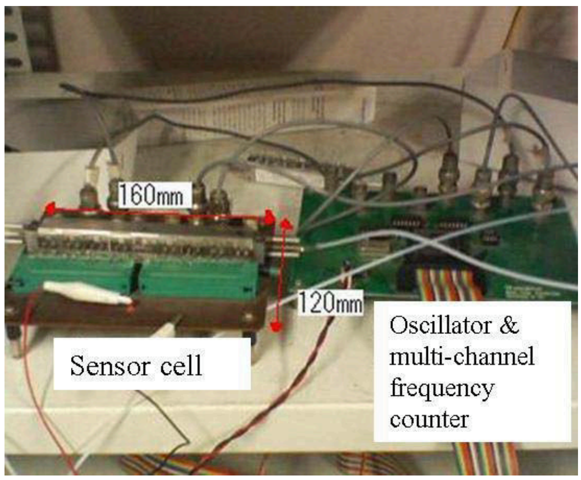

Figure 2 sensor cell and peripheral circuit

In this system, the odor concentration and the classification result are used as odor information. The detail for the analysis is described in the next section.

To record and transfer the movie and the odor information in real time, the software written in Visual Basic 6 (Microsoft Corp) was developed. This program continuously records, analyzes and transfers the data to the display system every second.

The movie taken by the web camera (BWC-130MH03A/BK, Buffalo) is once stored in a memory and then merged with the odor information. Then, the data are transferred to the display system at remote site via the Internet by using Windows Socket API (Winsock).

The image with the size of 160x120 has JPEG format. It is captured and stored into the memory every second. Thus, the image on the computer screen is updated every second. The streaming format of the movie was not used. Instead, the continuous static image was used since it is easy to synchronize odor concentration sequence with movie.

In this experiment, ADSL with the rate of 50Mb/s was used for the data transfer. The smell can be generated synchronously with the movie without the influence of Internet congestion.

Figure 3 shows the image of the odor classification interface on the computer screen. The lateral axis of the three graphs in that image is time. This figure appears during the real-time sensing and the elapsed time after starting the measurement is 64s in this figure. Left part of the image shows the sensor responses of the four QCM sensors. The sensor responses are highly fluctuated due to the air turbulence in the ambient air. Upper right part of the image shows the classified category. Lower right part of the image indicates the relative odor concentration. The odor classification algorithm is described later.

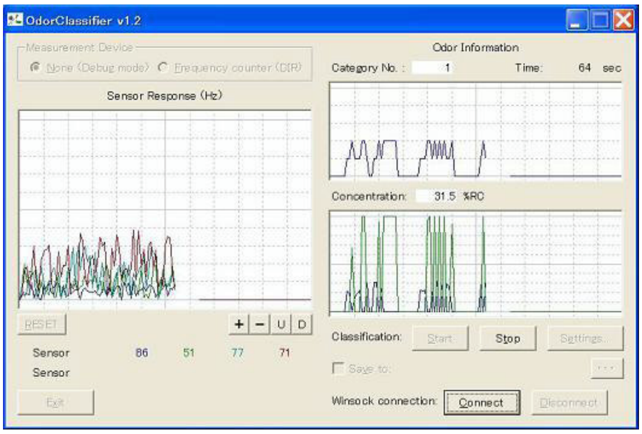

Figure 3 Image of odor classification interface on computer screen.

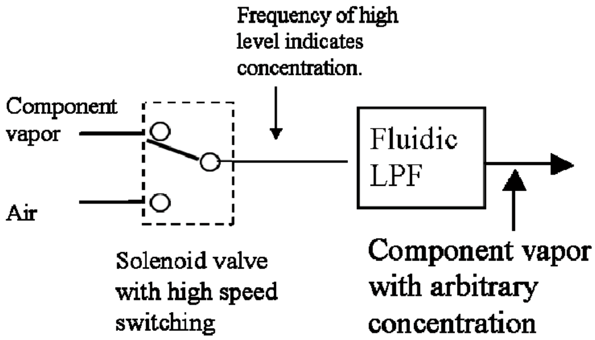

Figure 4 Principle of olfactory display using solenoid valves.

2.2. Display system

The display system receives the transferred data and presents them in real time. The system consists of a laptop computer, an olfactory display and a headset. The developed software was also written in Visual Basic 6. The received data are separated into two parts such as movie and odor information. The odor information consists of its concentration and the kind of odor.

The movie is simply shown on the computer screen at the rate of 1 frame/s using web browser. The odor is generated using the olfactory display using solenoid valves [10]. The principle of the olfactory display is illustrated in Figure 4. The dilution of the headspace vapor over sample liquid in a bottle with the air can be achieved by rapidly switching solenoid valves. When it is extended to multiple odor component system, any recipe of the blended odor can be realized. The current olfactory display can blend up to 32 odor components and its recipe can be updated every second.

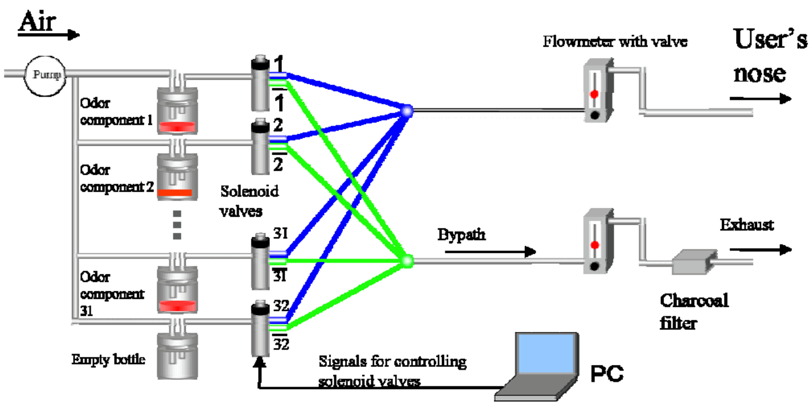

Figure 5 Structure of olfactory display

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The structure of the olfactory display is shown in Figure 5. This system has 32 channels, one for air and others for 31 odor components. The headspace over the liquid of odor component in each vial is flowed to either of the two odor paths, one to a user's nose and another one is bypath. The bypath vapor is exhausted through a char coal filter. Either of them is selected using a solenoid valve. The bypath is required here since the flow rate at the sample bottle should be maintained to avoid the concentration variation at the sample bottle even if the odor is not emitted to the user's nose.

The photo of the olfactory display is shown in Figure 6. 32 sample bottles are placed at the bottom. In the upper portion of the box, the manifold with 32 solenoid valves and the driver circuits for solenoid valves are placed although the upper portion cannot be seen in Figure 6.

The user can sniff the smell from the slit of the plastic adaptor placed at the microphone of the headset, connected to the olfactory display via Teflon tube.

Although the olfactory display can blend many odor components, only two odor components were used in later experiment. Two flavors were set at two vials and the function of blending was not used here for simplicity. Instead of it, the function of adjusting odor concentration every second was used in the present study.

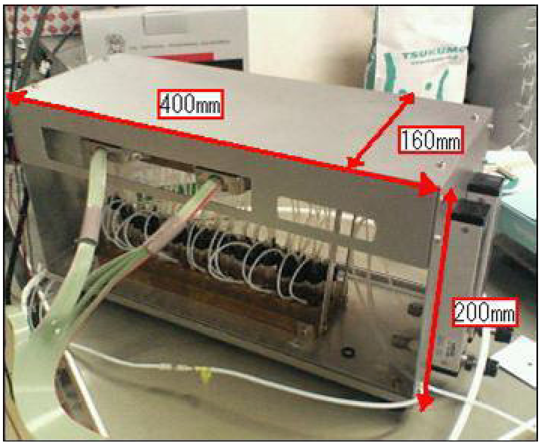

Figure 6 Photo of olfactory display

Although the control sequence of the solenoid valves was managed in the computer in ref [10], the current system has FPGA board (Altera, EP1C2Q240C8) in the olfactory display. The CPU core with peripherals such as serial interface and the parallel I/O was implemented into FPGA. After the CPU core (NIOS, Altera) receives the recipe information from the computer via RS232C interface, it generates bit stream to control the ON/OFF sequence of each solenoid valve. The program for the CPU core was written in C language.

After the introduction of FPGA into the olfactory display, the flexibility of the olfactory display increased. When people want to use that system, it is not necessary to consider the complicated control sequence of the solenoid valves. The olfactory display works after simply specifying the concentration sequence. After this improvement, the portability of the system became much better. Then, the compact version of the olfactory display was recently developed with the collaboration of the companies for the prototype before commercialization.

3. Odor-information analysis

The odor information handled here is a kind of odor and odor concentration. Odor identification is performed as follows.

3.1. Judgment of odor existence

First it should be judged whether the odor exists. When no odor is detected, the sensor response is quite stable. Although slight noise or drift sometimes appears, the fluctuation behavior is different from them when the odor is presented. The QCM sensor response to an odor in ambient air always rapidly fluctuates due to air turbulence [17]. The fluctuation of the sensor response is usually larger than the noise in the case of odor presence. The data for 5s were used to judge the existence of the odor. The threshold of the response variation in noise was set to 5Hz. That time span and the threshold were empirically determined. If the response variation exceeds the threshold three times during that time span, it is judged that the odor exists.

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3.2. Odor classification

Next step is the odor classification. We used LVQ (Learning Vector Quantization) neural network [18] to classify the odor since its algorithm is simple and easy to implement into a computer program in spite of its high classification capability.

In LVQ, multiple reference vectors are used. Each reference vector should belong to one of the classified categories. The input vector is classified as category of the nearest reference vector. We can obtain the classification result in real time by inputting the measured sensor responses to the network.

Since LVQ is a supervised learning algorithm, it requires the neural network training. In this system, a set of sensor responses was used as an input vector. In the training phase, only the nearest reference vector is updated so that the distribution of the reference vectors can match that of the input vectors.

3.3. Estimation of odor concentration

The odor concentration is estimated using the calibration curve. The calibration curve is defined as $f(x)$ where x is the relative odor concentration and y the magnitude of the sensor response. Therefore, the relative odor concentration can be estimated using the inverse function $x=f^{1}(y)$. We obtained the curve by measuring steady-state sensor response to the target odor at several concentrations. When the calibration curve is obtained, the olfactory display is used as odor generator for supplying the odor to the sensor at specified concentrations. We used the largest sensor response among four sensors to estimate the odor concentration to increase the accuracy.

In this system, we represent the odor concentration with the unit %RC, relative to the concentration of the pure odor without air dilution. When the estimated concentration exceeds 100%RC, the generated concentration is set 100%RC because it is not possible to generate the odor with the concentration beyond 100%RC. When no odor is detected, the generated concentration is set 0%RC.

4. Result of sensing

4.1. Preparation for LVQ

In this system, the odor information was analyzed and transferred to the display system in real time. Thus, we had to prepare for LVQ for the odor identification.

The LVQ requires a training data for the classification since it is a supervised training algorithm. We obtained the training dataset of each category by measuring sensor responses to the sample in the ambient air for 70s. Those sensor responses were used as pattern vector. Then, we selected 10 initial reference vectors for each category from the training dataset. Therefore we had 60 pattern vectors for each category to train the neural network. The network training was repeated 20 times in this experiment.

Figure 7 shows the scattering diagram for PCA (Principal Component Analysis) of the training data and the trained reference vectors. PCA is the dimensional reduction technique of the multidimensional data with the least information loss [19]. PC1 and PC2 in the figure are the first principal axis and the second one, respectively. It is often used to see the relationship among the data in two-dimensional space even if the dimension of the original data is high. In the present study, the dimension of the input and reference vectors is four.

Samples used here were orange and apple flavors. Figure 7 indicates that the clear pattern separation is obtained between the two categories. Since the pattern separation was clear, the classification of these two samples was 100% when the data were classified by LVQ. The data distribution of each category was striped shape because of odor-concentration fluctuation. It was also found that the reference vectors were correctly placed after training and covered the whole distribution of each category.

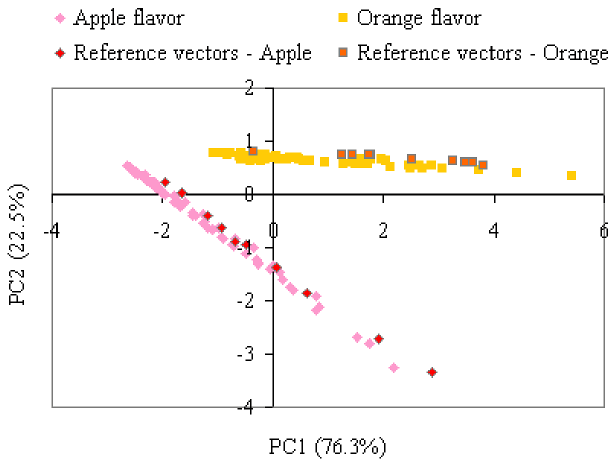

Figure 7 Scattering diagram of training data and reference vector after training for PCA

4.2. Demonstration of teleolfaction

We demonstrated the experiment on teleolfaction at Tokyo Big Sight (Koto-ku, Tokyo) during the Industry Academic Government Technical Exchange Fair 2007. We set the recording system at our laboratory and the display system at the remote site at that exhibition.

At the laboratory, the recording system was set in a wind tunnel with five sample vials. The vials were equally placed and the distance from vial to vial was 80mm. The photo of the objects is shown in Figure 8.

Two of them were filled with the samples of apple and orange flavors, respectively, whereas the others were empty. It was difficult to know which vials contained the liquid when people watched only the movie. The volume of each vial was 30mL. The sniffing point was the tip of Teflon tube. The tube was connected to the sensor cell shown in Figure 2.

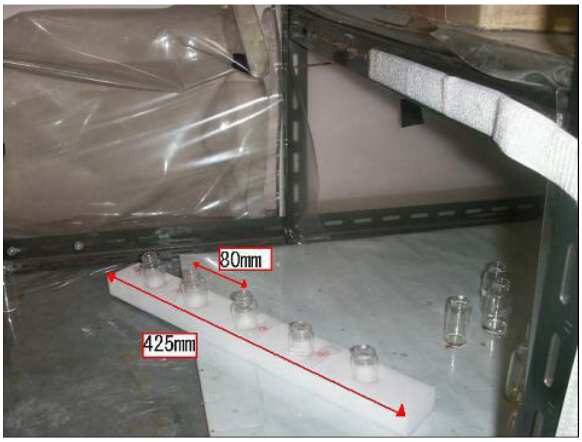

Figure 8 Photo of objects (vials) for sensing.

The tube was supported by the arm made of wood as is shown in Figure 9. The web camera was also set at the arm. It took the picture around the sniffing point. This arm was manually moved to make the sniffing point closer to the vial.

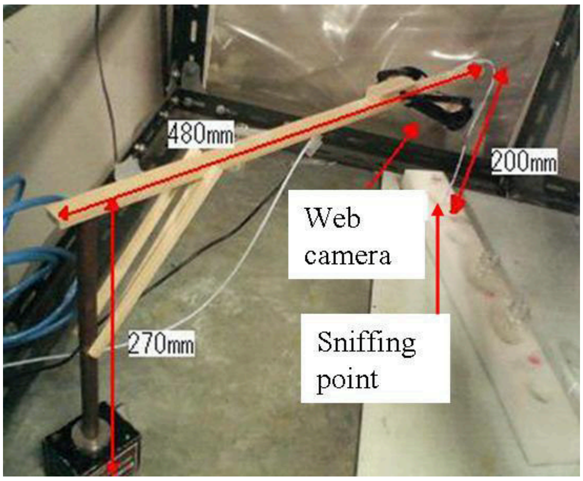

Figure 9 Sniffing point for sensing.

The image taken by the web camera is shown in Figure 10. The software used here was LiveCapture2. The sniffing point, i.e., the tip of Teflon tube was placed above the sample vial.

Figure 10 Captured image of sample vial in wind tunnel.

The booth at the exhibition is shown in Figure 11. A user cannot grasp the situation at remote sensing site only when he/she sees the image of sniffing point and sniff the smell at the same time. Thus another web camera was placed close to the wind tunnel to show the whole image of the objects.

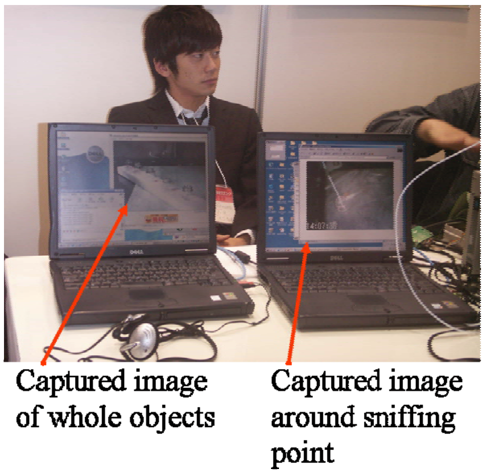

Figure 11 Booth at exhibition.

5. Questionnaire survey

We evaluated the capability of our system by a questionnaire survey at the exhibition. Two of five vials were filled with apple and orange flavors respectively, whereas others were empty. The sniffing point was manually made close to the vial individually together with taking the movie. People at the exhibition site sniffed the smell in real time sensed at the wind tunnel in our laboratory. Simultaneously, they could watch the movie taken there. The time for sniffing smell was approximately 10s and the time from vial to vial was approximately 5s.

They were requested to identify the vials with apple and orange flavors. Figure 12 shows the result of the questionnaire survey. Approximately 80% of people correctly identified the smell inside the vials.

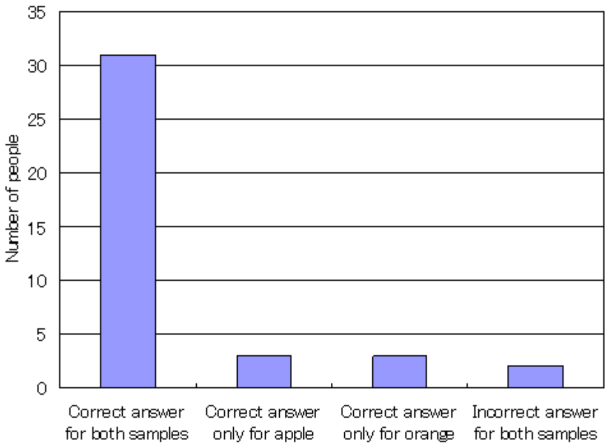

Figure 12 Result of questionnaire survey for odor identification by people at remote site.

Another question is whether movie is synchronized with smell. The result of the questionnaire survey is summarized in Figure 13. More than 80% people answered the synchronization worked well.

Other question is whether he/she feels more real after adding the smell to the movie. The result of the questionnaire survey is shown in Fig.14. More than 80% people also answered positively to this question.

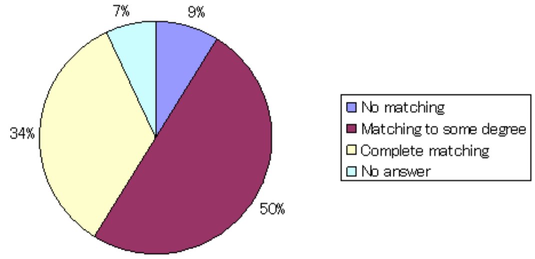

Figure 13 Result of questionnaire survey for synchronization of movie with smell.

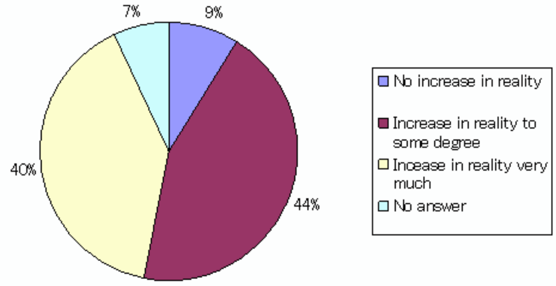

Figure 14 Result of questionnaire survey for increase in reality after adding smell to movie.

6. Conclusion

We have developed the teleolfaction system with concurrent visual information. This system can record and present a movie with smell to users at remote site in real time via the Internet. In recording system, QCM gas sensors with LVQ neural network were used to classify smells and estimate odor concentration. In the display system, the olfactory display using solenoid valves was used to present smell with time-varying concentration sequence. The questionnaire survey reveals that users can perceive olfactory and visual stimuli even at the remote site.

In the future, more sophisticated algorithm to enhance the robustness against concentration fluctuation will be included [20]. Moreover, the location of the sniffing point will be remotely controlled by a user to enhance the interactivity.

When the odor is mixed in the ambient air, an odor recorder to record smell as well as reproduce it can be used [21]. In the environment of the ambient air, the odor concentration is highly fluctuated. Although the technique to record odor with rapid change of the concentration and recipe was proposed [22-23], we focused on the category classification and odor concentration change without mixing odor in the present study. The reproduction of mixed odor at remote site is another future problem.

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