

Development of Olfactory Display Using Solenoid Valves Controlled Atomization for High Concentration Scent Emission

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Abstract

This paper reports on the introduction of using atomization technique controlled by high-speed switching solenoid valves to present smells. Even though atomization has been widely used to release smells in commercial aroma diffusers, intensity of the released odor cannot be controlled. In this paper, the high speed ON/OFF switching of the solenoid valves enables the capability to control odor intensity precisely and rapidly and the atomization enables emission of high concentration odors compared with odors generated from natural evaporation method. The proposed olfactory display was evaluated by using an odor sensing system composed of a quartz crystal microbalance (QCM) gas sensor. As a result, the reproducibility and the capability to present high concentration odors with adjustable intensity of the proposed olfactory display were confirmed.

Categories and Subject Descriptors: H.4.m [Information Systems Applications]: Miscellaneous

1. Introduction

Human perceives the world through five senses: vision, audition, olfaction, gustation, and tactile perception. Information from any senses cannot be fully compensated by the others, for example, the sweet fragrances of ripe fruits or the fresh smell of a warm sea beach cannot be perceived via other senses. Even though the study on olfaction relating technologies such as odor sensing devices and odor presenting devices are premature compared with the technologies based on vision and auditory, the number of these researches have been substantially increased in the past decade.

For the latter, odor presenting device which is also called olfactory display can be used in various applications. For example, Okada et al. introduced the concept of using odor presentation as a mean for health checkup since a decline in olfaction is an early symptom of diseases such as Alzheimer's and Parkinson's diseases [FSO13]. Akira et al. examined the influence of smells in advertising by release smells with an image content on a digital signage and evaluate the eye catching and memorization of the people walking around. Their results suggest that presenting smells with an image content can increase the viewers' interest and the memorization becomes easier [TKYT12].

Bodnar et al. explored the properties of different modalities as notification mechanism in messaging system. Their results suggest that the odor stimuli are optional potential modality for notification as it produces a less disruptive effect to a user compared with other modalities [BCN04]. Miguel et al. conducted an experiment to examine the usability of odor presentation in a classroom. The result

suggests that olfactory information can be supplement or complement other learner channels and stimulate their affection and cognition [GEA*08].

Hendrik et al. investigated the usefulness of releasing pleasant scents in a nightclub. Their results suggest that nightlife experience including dancing activity, evaluation of the evening, evaluation of the music, and mood of the visitors can be improved by the environmental fragrance [HKD11]. Yanagida et al. conducted an experiment to examine the capability to use odor presentation to prevent driver from dozing and help them remain alert. The results show that alertness level of a driver can be revived and maintained by presenting fragrance which invokes a cool feeling such as peppermint intermittently [OWA*09].

Thus, it is obvious that odor presentation can be utilized in a variety of applications. Recently, various odor reproduction mechanisms have been proposed based on different techniques. Each approach has its own merit which suits for some specific application. For example, Okada et al. have developed the olfactory display based on inkjet system [SOB*09]. Liquid odorants are filled into the inkjet devices instead of inks. The device can emit odors by ejecting tiny droplets of the odorants with amount of picolitre intermittently. The odor reproduction based on this technique can overcome the olfactory fatigue which is the temporary inability of odor perception to distinguish smells after exposure for a period of time.

Kim et al. have developed the olfactory display based on smart material such as functional high polymer [KCN*09]. The device is composed of metal containers filled with encapsulated temperature

responsive hydrogels and Peltier device located under it. The release of aroma can be controlled by adjusting the temperature to change the phase transition of the hydrogels between sol and gel. The device works soundlessly and concentration of the released odors can be adjusted; however, the start and stop of odor release and the change of controlled concentration cannot be performed rapidly as the reproduction is based on heating and cooling.

Yanagida et al. have developed the scent projector [YKN*04]. This device can present odors both temporally and spatially by using an air cannon to launch a vortex ring with scented air inside to a remote target position or walking person. Ishida et al. have developed the smelling screen [MY113]. The system is composed of fans on each corner of the screen which generate airflows to construct an odor distribution on the two-dimension display screen so that a user can feel as if an odor is spread from a specific image shown on the screen.

Nakamoto et al. have developed the olfactory display using solenoid valves which uses an air pump to blow liquid odorants filled in bottles to generate odors [NP07]. The odors are supplied to solenoid valves with two states of ON and OFF through tubing. Odor concentration can be adjusted by controlling the switching state of the solenoid valve. Even though this olfactory display can control concentrations of the release odors, it has a difficulty to release odors of low volatile odorants with sufficient concentration as the odor reproduction is based on natural evaporation.

The same group also developed the olfactory display using inkjet devices and a heater [NTY04]. Liquid odorants are filled into the inkjets so that their small droplets are ejected onto the heater located below to be vaporized into smells. Even though this olfactory display can present scents of low volatile odorants, the system is difficult to be handled when the number of odorants are increased and the heater radiates heat to the nearby environment.

To overcome the problem, Yossiri and Nakamoto have developed the olfactory display using surface acoustic wave (SAW) device and electroosmotic micro pump [AN11]. Liquid odorants are filled into the micro pump which ejects the liquid droplets onto the SAW device located below. If the SAW energy is sufficient, the leaky SAW radiates a longitudinal wave into the droplets which cause them to be atomized into smells without heat radiation to the nearby circumstances. However, the system becomes difficult to handle when the number of odorants are increased because impedance of the SAW device changes unpredictably due to the various liquid odorant mixtures on its surface.

It is clear that various odor reproduction techniques have been proposed to fulfill a variety of applications. In any applications, one of the essential requirement is the sufficient concentration of the released odors. However, low volatile odorants are widely used in various works, for example, in flavor and fragrance, and food and beverage industries. As their boiling points are high, releasing their odors at high concentration is difficult.

In this paper, the concept of olfactory display using solenoid valves controlled atomization for high concentration scent emission was proposed. Even though atomization has been widely used to release smells in commercial aroma diffusers, intensity of the released odor cannot be controlled. Thus, high speed solenoid valves were used to control odor concentration in this study. In the experiment, an odor sensing system was used to evaluate the reproducibility of the proposed concept, capability to present scents of low volatile odorants with high concentration, and capability to control concentration of the released odors.

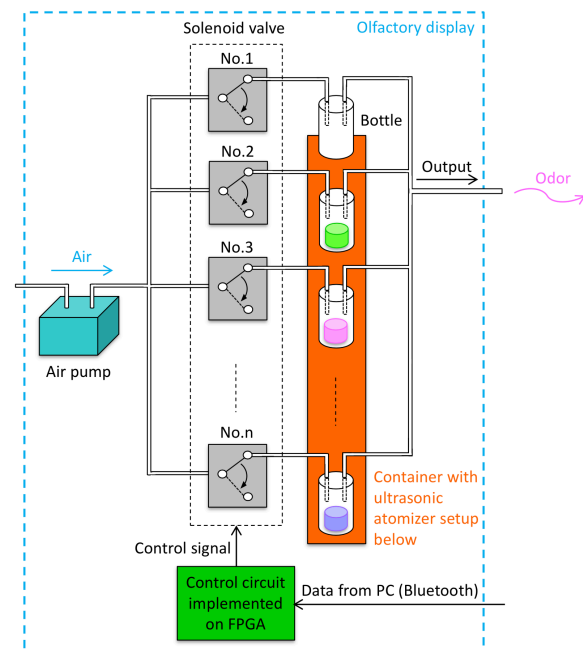


Figure 1: Odor reproduction mechanism of olfactory display using solenoid valve controlled atomization proposed in this study.

2. System Overview

The mechanism of n-channel odor reproduction proposed in this study is shown in Figure 1. The liquid odorants are filled into bottles located in a 100 mL container with 32.15 cm² of the bottom area filled with water that works as a medium for ultrasonic radiation. A 2.4 MHz 13.2 W ultrasonic atomizer (HM2412, Honda Electronics) is installed at the bottom of the container. When the atomizer is turned on, the ultrasonic wave propagates upward into the bottom surface of the bottles and its energy transfer causes liquid odorants inside the bottles to be atomized into smells.

Based on this technique, even low volatile odorants can be atomized forcibly. Moreover, as water is the only medium for ultrasonic radiation in the system, the efficiency of the atomization does not depend on the liquid odorant unlike the olfactory display using SAW device. The generated odors are supplied through tubing by means of air flow generated from the air pump. As the solenoid valves are located between the air pump and the bottles, the ON and OFF states of the solenoid valves enable the start and stop of odor presentation and by controlling the switching rates of the solenoid valves, concentration of the released odors can be adjusted. The solenoid valves used in this study are 3.3 V 850 mW low power 2-way solenoid valves (LHDB0352115H, Lee) with 4 ms of switching speed. To avoid cross-contamination between odor samples the solenoid valves are set up prior to the bottles and tubing is used as less as possible.

The switching rates were controlled by the duty cycle of the pulse width modulation (PWM) signal from a control circuit implemented on an FPGA board (DE0 Nano, Terasic). Concentration of the odors released from the proposed olfactory display can be adjusted between 0 – 100% with 1% of resolution and 10 ms of temporal resolution. To maintain the stable airflow in the system, the first bottle was set to be empty and the remaining percent concentration is assigned to the solenoid valve connected with it. A

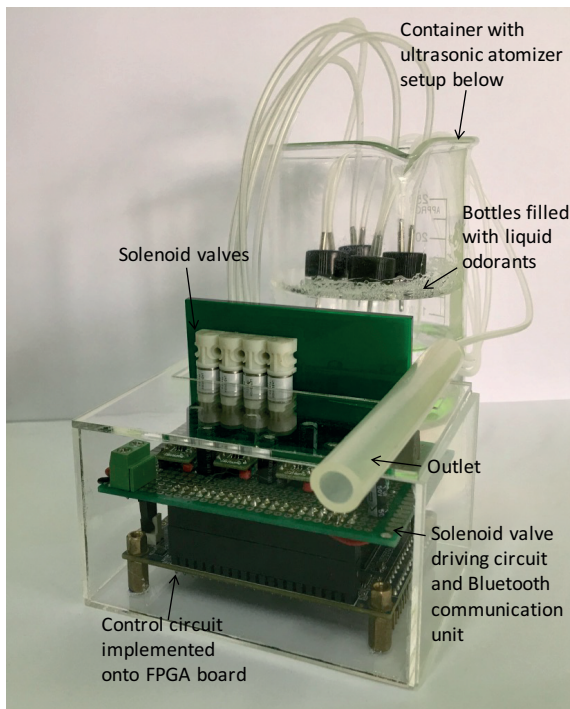


Figure 2: An actual image of structure of the composed olfactory display using solenoid valve controlled atomization proposed in this study.

graphic user interface (GUI) software was developed on a PC so that a user can control odor concentration conveniently. The proposed olfactory display communicates with a PC via Bluetooth communication. An actual image of the 4-channel olfactory display proposed based on this concept is shown in Figure 2.

3. Experimental Setup

To evaluate the proposed system, an odor sensing system was used instead of the widely used sensory test as it can measure the temporal change of the odor concentration rapidly and quantitatively with high reproducibility whereas human perception is influenced by olfactory fatigue and its variation from person to person is considerable. The whole experimental setup is shown in Figure 3.

The odor sensing system was composed of a QCM gas sensor installed in a flow cell built from polylactic acid (PLA) by using a 3D printer. The QCM sensor used in the experiments was AT-CUT polished gold electrode with 20 MHz resonant frequency and without deposition of sensing film. It was placed on an oscillator circuit so that the resonant frequency is shifted when the odor concentration nearby the sensing area of the sensor changes due to mass loading effect.

The resonant frequency was measured by using a frequency counter (53210A, Agilent) with 0.1 s of temporal resolution. The measured data were transferred to a computer via USB memory as a csv file. During the experiment, the temperature control was not performed and the flow cell was connected directly to the outlet of the olfactory display so that no gas leak occurred and the flow rate of the scented air was measured by using a flow meter (LZB-2, WELL Flow Instrument). The flow rate of air flow in the system was 150 mL/min in all experiments in this study.

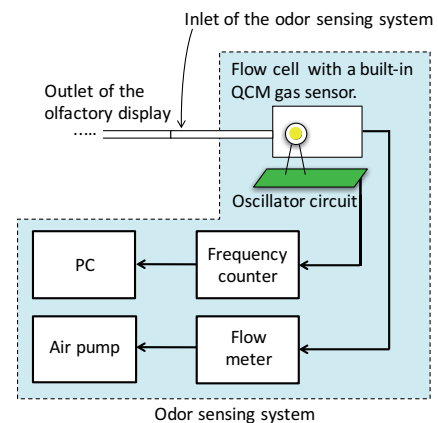


Figure 3: Block diagram of the odor sensing system used in this study.

4. Experimental Result and Discussion

In the experiment, four essential oil: ylang ylang, bergamot, eucalyptus, and peppermint were used for sample preparation. They are low volatile odorants with boiling points at 264, 159, 175, and 209 °C, respectively. The essential oils were diluted in ethanol with 10% concentration. The PWM signal was applied into the solenoid valve to control the concentration of the released odor.

In the first experiment, ethanol was presented with 80% of duty cycle of PWM signal for 1 s 10 times. The duration between each exposure was set to 40 s so that the recovery time can be clearly observed. The experiment was conducted without driving the ultrasonic atomizer. Thus, the odor reproduction was based on natural evaporation. The experimental result is shown in Figure 4. From the figure, the abrupt peaks of the sensor responses can be observed when the odor was exposed and it recovered to the baseline in a short time. Even though the baseline was shifted in accordance with the time, it does not imply any problem since frequency shift in digit can occur in regular QCM sensor usage.

In the next experiment, 10% of peppermint diluted with ethanol was presented with 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% of duty cycle of PWM signal, respectively. The odor at each concentration was presented for 1 s and the duration between each exposure was set to 40 s. The experiment was conducted without driving the ultrasonic atomizer. The result is shown in Figure 5. From the figure, the abrupt peaks of the sensor responses can be observed when the odor was exposed and the responses were nearly absolutely recovered to the baseline. It means that the released odor passed through the sensor without contaminating on its surface. Thus, the reliability of the odor sensing system used to evaluate the proposed olfactory display was confirmed.

In the next experiment, 10% of peppermint diluted with ethanol was presented with 100% of duty cycle of PWM signal for 4 s 6 times. The duration between each exposure was set to 40 s. The experiment was conducted with driving the ultrasonic atomizer. Thus, the odor reproduction was based on atomization. The result is shown in Figure 6. From the figure, the abrupt peaks of the sensor responses can be observed when the odor was exposed and the responses were nearly absolutely recovered to the baseline within a short time. It means that even the odor reproduced from atomization can pass through the sensor without contaminating on its surface. Therefore, the measurement result is reliable. Furthermore,

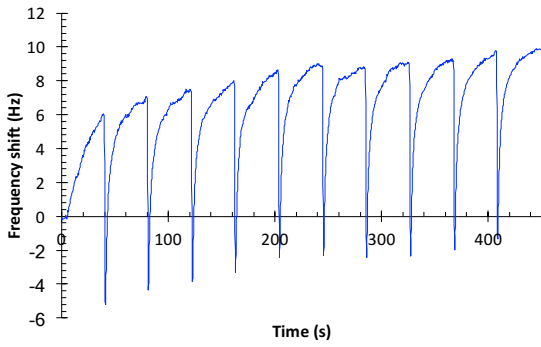


Figure 4: Sensor response to ethanol exposed for 1 s at 80% of concentration without atomization.

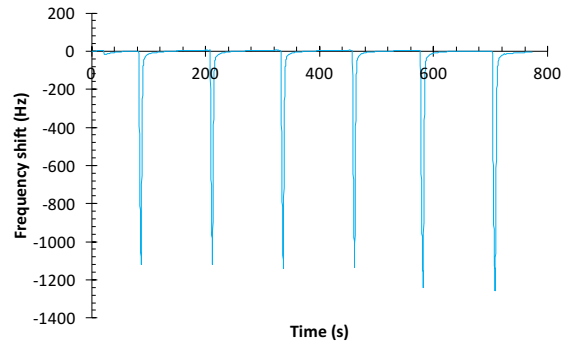


Figure 6: Sensor response to the 10% of peppermint diluted with ethanol exposed for 4 s at 100% of concentration with atomization.

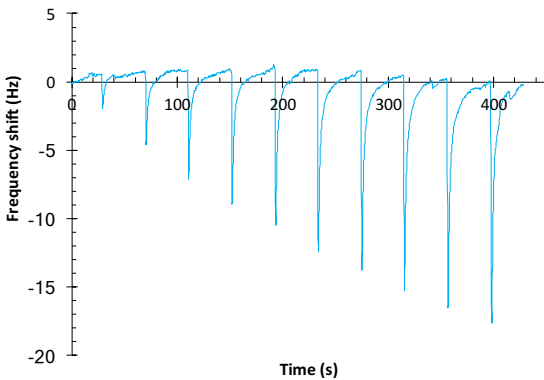


Figure 5: Sensor response to the 10% of peppermint diluted with ethanol exposed for 1 s at 10 – 100% of concentration without atomization.

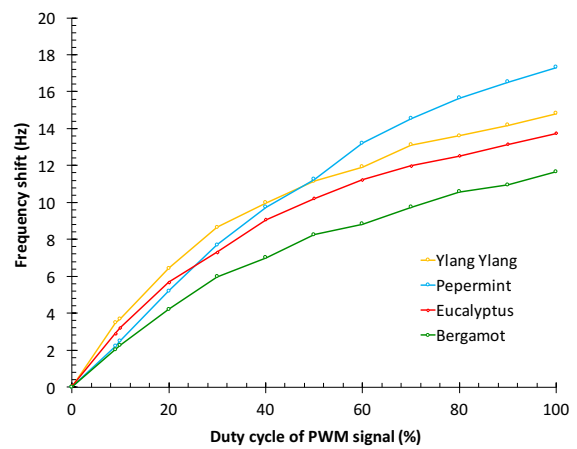


Figure 7: Summarization of the averaged amplitudes of sensor responses to the 10% of ylang ylang, bergamot, eucalyptus, and peppermint diluted with ethanol exposed for 1 s at 10 - 100% of concentration without atomization.

amplitudes of the sensor responses to the odor exposures were roughly equal. Thus, the reproducibility of the proposed olfactory display was confirmed. Moreover, the considerably high amplitudes of the sensor responses were obtained compared with the result in Figure 5. It confirmed that the proposed olfactory display can generate the odors of low volatile odorants rapidly at high concentration. Furthermore, since no interference occurred in the sensor response in Figure 6, it can be concluded that the proposed olfactory display can atomize liquid odorants into odors in gas phase completely without producing small particle in liquid phase.

Eventually, the 10% of ylang ylang, peppermint, eucalyptus, and bergamot diluted with ethanol were presented with 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% of duty cycle of PWM signal, respectively. The odor at each concentration was presented for 1 s 4 times and the duration between each exposure was set to 40 s. The experiment was conducted without driving the ultrasonic atomizer. The summarization of the averaged sensor response amplitude is shown in Figure 7. From the figure, the capability to control concentration of the released odor can be observed. Then, the 10% of ylang ylang, peppermint, eucalyptus, and bergamot diluted with ethanol were presented with 40, 50, 60, 70, 80, 90, and 100% of duty cycle of PWM signal with driving the ultrasonic atomizer, respectively. The

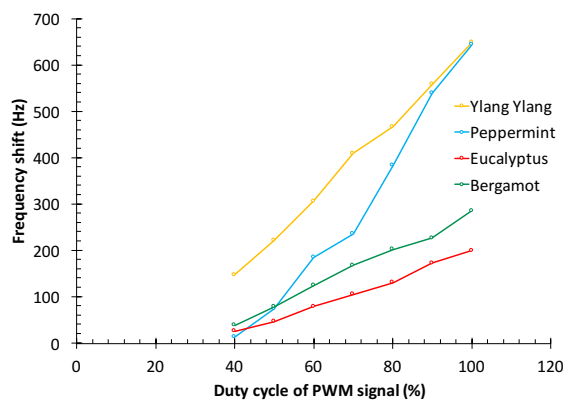


Figure 8: Summarization of the averaged amplitudes of sensor responses to the 10% of ylang ylang, bergamot, eucalyptus, and peppermint diluted with ethanol exposed for 1 s at 40 - 100% of concentration with atomization.

timing condition was not changed from the previous experiment. The summarization of the averaged sensor response amplitude is shown in Figure 8. From the figure, the relatively high amplitudes of the sensor responses can be observed. It confirmed that the proposed olfactory display can generate the odors of low volatile odorants at high concentration. The capability to control concentration of the released odor with roughly linear relationship between odor concentration and % duty cycle of the PWM signal can also be observed. It confirmed that the proposed olfactory display can also control the concentration of the odor released from ultrasonic atomization.

5. Conclusion

In the present study, an olfactory display using atomization technique controlled by high-speed switching solenoid valves was proposed. The odor reproduction was performed by atomizing liquids odorants into smells using an ultrasonic sonic atomizer. As water is the only medium for ultrasonic radiation in the system, the efficiency of the atomization does not depend on the liquid odorant unlike the olfactory display using SAW device. Concentration of the reproduced odors can be adjusted by controlling the switching rates of the high-speed solenoid valves connected to the odorant bottles. The experiments were conducted using an odor sensing device composed of a QCM gas sensor. The experimental results confirmed that the proposed olfactory display can generate high concentration odors from low volatile odorants efficiently and rapidly with the capability to control the odor concentration. The result also shows that the released odors are absolutely in gas phase without liquid particle that causes users feel uncomfortable when they inhale it. The proposed technique to present smells is expected to be utilized in the applications in which the sufficiently high concentration of the released odors is significant.

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