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Incorporating Olfactory into a Multi-Modal Surgical Simulation

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SUMMARY This paper proposes a novel multimodal interactive surgical simulator that incorporates haptic, olfactory, as well as traditional vision feedback. A scent diffuser was developed to produce odors when errors occur. Haptic device was used to provide the sense of touch to the user. The preliminary results show that adding smell as an aid to the simulation enhanced the memory retention that lead to better performance.

key words: *olfactory, haptic, surgical simulation, mulitmodal interaction*

1. Introduction

In recent years, simulation-based training has emerged as a potential method, and the value of simulation-based learning has been more widely accepted [1]. Simulation can be a safe, cost-effective, customizable, and easily accessible tool for gaining experience in surgery.

The connection between smell and memory has been well documented [2], [3]. In addition, incorporating aromas into virtual environments has been demonstrated to be an affective memory enhancer, and demonstrated that increasing the modalities of sensory input (tactile, olfactory, etc.) increased the sense of presence [4].

In the past years, surgical simulation has undergone many changes. It becomes more realistic with better graphics and ability to provide interaction with the simulation. However, surgical simulation still missing the olfactory sense and the accurate haptic sensation, which are two indispensable senses that usually the surgeon rely heavily on them to perceive and interact during any surgical procedure. Previous studies proved the effect of these two senses in the process of training [5], [6].

This paper proposes a novel multimodal interaction whereby haptic, olfactory, and vision senses are all incorporated in a medical surgery simulation. Adding the sense of smell into existing patient and haptic surgical simulators as a novel way to enhance the fidelity of the virtual experience, in addition to helping medical students begin to recognize the important role that the sense of smell plays in the field of medicine. Many experiments have been carried out to demonstrate that incorporating the sense of smell into virtual surgical simulation can be an effective memory enhancer. Adding aromas to such a system increase the memory retention of trainee thus reduces surgical errors.

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2. Related Work

In engineering, there have been several approaches in developing computer aided surgical training. Most of those surgical training systems have one or two feedback interactions. Spencer et al. [5] proposed a model of a surgical simulation that incorporates olfactory technologies into haptic surgical simulators, nevertheless, his efforts stopped at idea presentation since no implementation or methods were proposed on how to achieve his model. Other previous surgical simulation training systems were concentrating on providing one or two feedback interaction. The role of haptics within virtual medical training applications was discussed in [7]. Dan Morris et al. [8] and Halabi et al. [9] provided only visual and haptics feedback in their simulations. All the surgical simulators proposed in the last decade did not incorporate the sense of smell. This is might be due to the technical difficulties in developing computerized, scent-producing devices. Regarding the olfaction devices, some devices were developed for other applications using different methods. One of the methods proposed was using Electro-osmotic (EO) pump, a Surface Acoustic Wave device (SAW), and a fan. With the help of fan, the smell is directed to user's nose [10]. This approach is very complicated compared to other available methods. Another method to display scents was using air pumps. This method was developed by Tanikawa and some colleagues in University of Tokyo [11]. Their wearable olfactory display was used to produce odor according to the user position. However, in our device the odor is produced according to the user's interaction with the haptic device and the 3D model. Moreover, the odor intensity controls the speed of the micro air pump using pulse width modulation of the microcontroller (PWM). Also, in their design, the odor filter unit is far away from the user's nose and this may cause a loss in the odor intensity; to overcome this disadvantage the odor filter is designed to be close enough to the user's nose. Additional feature of our scent diffuser is that it is wirelessly communicates with the Laptop using Bluetooth connection that can enable free movement and portability.

3. System Overview

We developed a surgical training system that simulates appendix removal surgery and incorporates olfaction, vision, and haptic sensations. The user has three different responses: force feedback from the haptic device, smell feedback from the olfaction device, as well as traditional visual feedback.

3.1 High Level Architecture

In this system, the user wears the scent diffuser and performs surgery on simulated body's patient through moving the stylus of the haptic device. The user is able to sense different textures or materials of simulated organs through the stylus of haptic device. When the user performs a wrong task such as cutting skin instead of appendix, an odor is diffused towards user's nose indicating an error has occurred. A high level architecture of the system is shown in Fig. 1.

3.2 Graphics and Haptic Module

For the graphics module, 3D anatomy models were acquired for a male body with its digestive system. The appendix has been edited to look infected. Each simulated organ has a different texture and programmed to have different force feedback, i.e., appendix is more squishy than skin. PHANToM is used as a haptic device to add haptic interaction to the simulator. Figure 2 shows the simulator interface. The trainee interacts with the haptic device to manipulate the 3D model of the organ. When the trainee performs an action, forces calculated according to haptic rendering method.

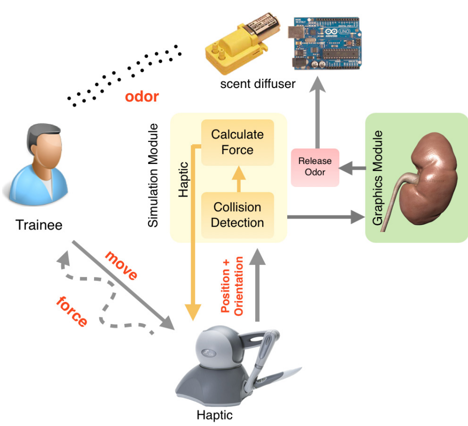

Fig. 1 High level architecture.

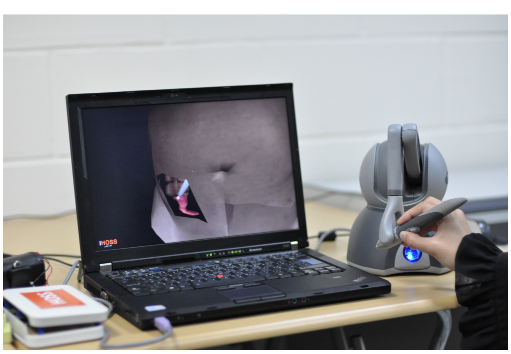

Fig. 2 Snapshot of the graphical user interface.

3.3 Scent Diffuser Module

A scent diffuser device was developed to be able to diffuse smell in case of wrong action. Arduino/PIC microcontroller is used to control pneumatic actuators that in turn control the release of different scents. Arduino is connected to the PC using Bluetooth in order to receive the proper commands on when to release the scent and at what intensity. The current design consists of four air pumps; therefore, it can release 3 different scents plus one for fresh air. Each scent is triggered by certain action in the simulator. An extra pump were used to release fresh air before diffusing scent to avoid mixing scents and ensure that the atmosphere is clear.

Scent diffuser module mainly consists of Micro air pumps (Enomoto Micro Pump, CM-15) and odor storage units. The air pumps used are light and small, in order to make it wearable. The odor storage unit consists of cotton soaked with an odor. Three odor filters are used to store odors. Ardiuno UNO Microcontroller is used to control the DC motor driver air pumps. An AND gate is used to turn on/off the DC motors. Puls Width Modulation (PWM) is used to control the intensity of the airflow by controlling the voltage at the DC motors. Arduino Bluetooth shield is used to establish wireless communication between the Laptop and the microcontroller and thus make the whole scent diffuser portable. The scent diffuser is triggered according to user's interaction with simulator. When the user performs a wrong task, the air pump is triggered and air flows through the odor filters. This air is mixed with odor in storage unit. As a result, a scent is released at the end of the pipe near user's nose. Figure 3 shows the hardware components of the scent diffuser.

The whole scent diffuser prototype can be seen in Fig. 4. The pipes ends are fixed to headphone so that the user can wear the scent diffuser and the flow of the air will be directed toward the nose. The final unit is compact and the weight is less than 600g.

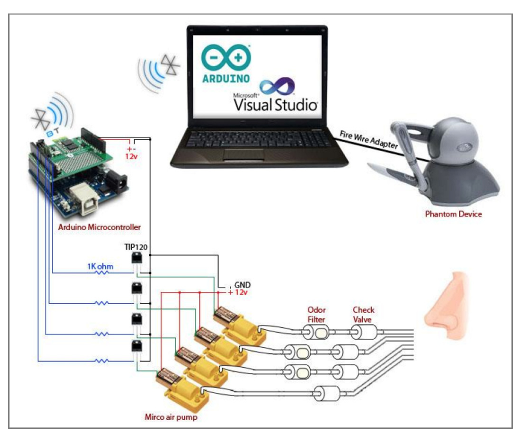

Fig. 3 Hardware design of the scent diffuser.

Fig. 4 Scent diffuser unit.

Table 1 Questionnaire rating.

Subjective measures	Scale	Subjective measures
Odor easily recognized	7–6–5–4–3–2-1	Not easily recognized
Convinced force	7–6–5–4–3–2-1	Not convinced
Satisfied	7–6–5–4–3–2-1	Not satisfied

Table 2 Descriptive statistics about the subjective measures.

	N	Minimum	Maximum	Mean	Std. Deviation
Odor	10	3	5	4.60	.699
Feeling	10	3	5	4.00	.667
Satisfaction	10	5	7	5.80	.919

4. Evaluation

4.1 Experimental Procedure

Five minutes were spent explaining the experiment procedure, and another five minutes were allotted to give the participants time to familiarize themselves with the haptic device, the virtual environment, and the scent diffuser. This is to avoid negative effects of each subject's learnability curve. Otherwise, the result will vary depending on how familiar the person is with the simulator. The experiment task was to cut the appendix according to a correct path and avoid cutting any of the surrounding skin. If the trainee cut the wrong area, a certain odor is diffused indicating that an error has occurred. Acetone, vinegar, and cleaning agent were used as an odor, however, further study is needed to replicate different smells. The experiments were carried out over 10 female subjects of ages between 20 and 25 years with background in engineering.

4.2 Subjective Evaluation

To test the usability and the user experience, three main subjective measures were tested: odor recognition, quality of haptic feeling, and overall satisfaction. The subjects were asked to rate their answers on a scale 1–7 as shown in Table 1. The subjects could easily recognize the odors (mean = 4.6, SD = 0.699) as show in Table 2, but only the acetone odor had a lower recognition time, which affected the overall recognition. In fact, the subjects could recognize the smell but it took them some time as they expressed after finished with the experiment. The feeling measures to what extent the subjects were convinced of the presented haptic sensation for different organs was realistic (mean = 4.0, SD = .667). The subjects said that they could feel the difference in sensation between different organs. Finally, the satisfaction measure in Table 2 shows that the overall satisfaction of the user experience for the whole system as a training simulator was (mean = 5.8, SD = .919). Most of the subjects showed interest in the system and the way it works. Figure 5 shows the subjective evaluation for the above three measures based on the result in Table 2.

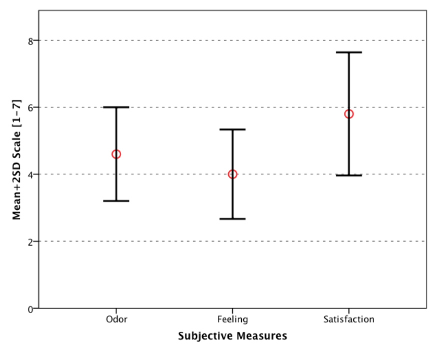

Fig. 5 Subjective evaluation according to the questionnaire. Values represent (M ± SD).

4.3 Evaluation of Olfaction

Many studies had explored the effect of haptic, vision and both modals on the overall interaction. In this work we introduced olfactory sense and combined it with haptic and vision in a surgical simulator. Therefore, we were eager to verify the effectiveness of such multi-modal interaction on the overall performance. We focused on evaluating the effectiveness of olfaction as an aid for memory retention and on what extent affect the accuracy in performing a task. Different subjects were asked to perform the same surgical task described in the experimental procedure with three feedback modes: olfactory only, vision only, and both olfactory and vision in which they carried out randomly and without a specific order for each subject. In the three modes haptic was always presented since we intended to focus on the olfactory sense.

4.3.1 Accuracy

In each of the aforementioned three experimental modes, the accuracy were measured by recording each subject's trajectory coordinate and comparing it with the correct path

Table 3 Descriptive statistics about memory retention and interaction modals.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Olfactory	20	.70	.470	.105	.48	.92	0	1
Vision	20	.40	.503	.112	.16	.64	0	1
Olfactory+Vision	20	.80	.410	.092	.61	.99	0	1
Total	60	.63	.486	.063	.51	.76	0	1

Table 4 ANOVA result for the memory retention.

	Sum of Squares	df	Mean Square	F	Sig.
Between	1.733	2	.867	4.049	.023
Within Groups	12.200	57	.214		
Total	13.933	59			

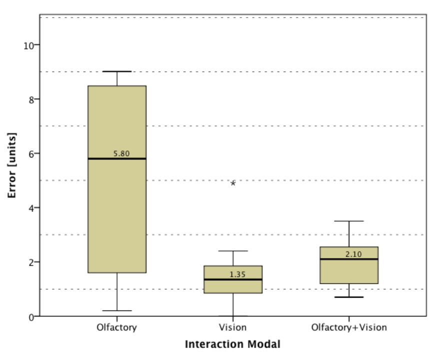

Fig. 6 The accuracy for the each interaction modal. Values represent (M ± SD).

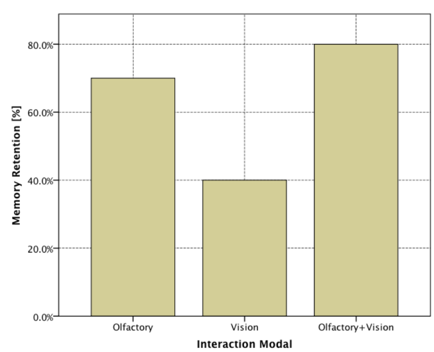

Fig. 7 The memory retention for different interaction modals.

for cutting, hence the error is calculated based on the difference between the two trajectories. The subjects repeated the tasks for two trails to consider the effect of training. The results in Fig. 6 show that the accuracy for vision is almost the same as for both olfactory and vision. This means that adding olfactory sense did not had a prominent affect in increasing the accuracy of performing the task. However, we can notice how wide is the variance of accuracy when only olfactory interaction modal used. This is reflects a big differences among users when it comes to accuracy. Therefore, olfactory alone is very subjective but combined with other interaction modals can be very effective.

4.3.2 Memory Retention

We mentioned an established link between memory and smell and proposed the smell as a memory enhancer for training. Experiment has been performed to verify this hypothesis. Using the previous experimental setting, in each mode, the subjects were asked after two hours of performing the task if they still remember the error made and the position where they committed the error. In olfactory mode the subjects were able to smell an odor indicating that they committed an error at that position. In vision only mode, the subjects were able to know that they committed an error by noticing the change in the color of the tool. In both olfactory and vision mode, both feedbacks were presented to the subjects. Table 3 shows complete statistics result related to memory retention for each interaction modal. The results showed that the subjects were able to remember the position of the committed error in olfactory plus vision mode more than that of the vision mode as shown in Fig. 7 with (mean = .80, SD = .410). Olfactory mode comes second with (mean = .7, SD = .470). The lowest score for memory retention was for vision mode (mean = .4, SD = .503). One-way ANOVA test was used to prove that there was a statistically significant difference between groups mean ($F(2, 57) = 4.049$, $p = .023$) as can be seen in Table 4. A Tukey post-hoc test revealed that the memory retention was statistically significantly the highest for vision plus olfactory (0.80 ± 0.410, $p = .022$) as can be seen in Table 5. There were no statistically significant differences between the olfactory and vision groups ($p = .110$), and olfactory and ol-

Table 5 Multiple Comparisons to show if there is a statistically significant difference between groups.

(I)Interaction Modal	(J)Interaction Modal	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Olfactory	Vision	.300	.146	.110	-.05	.65
	Olfactory+Vision	-.100	.146	.774	-.45	.25
Vision	Olfactory	-.300	.146	.110	-.65	.05
	Olfactory+Vision	-.400*	.146	.022	-.75	-.05
Olfactory+Vision	Olfactory	.100	.146	.774	-.25	.45
	Vision	.400*	.146	.022	.05	.75

factory plus vision groups (p = .774). This strongly supports our argument that smell increases the memory retention and it can enhance the performance in training simulators. However, it has to be combined with vision to achieve significant result. In addition, the result suggests that adding the sense of smell enhances the memory and helps trainees to better remember where and when they committed mistakes. This will eventually increase the efficiency of any training simulation.

5. Conclusion

The paper presented a multimodal interaction surgical training simulator that incorporates vision, touch, and smell sensations. The novelty of the system is combining all of these sensations in one simulator. We proposed a new design for a scent diffuser in which it was simple, compact, and portable at the same time. The efficiency of the scent diffuser was evaluated during many tests. Incorporating more senses takes the surgical simulation to the next level and increases its efficiency. Many experiments have been carried out to verify the effectiveness of such multimodal interaction. Subjective evaluations suggested that high percent were convinced that the simulator provided very realistic feeling and interaction. Smell plays a major role in memory retention. The vision scored lower than the smell with 0.4 remembrance; meanwhile it was 0.7 in smell only mode. The remembrance increased to 0.8 when combining both vision and smell together. All these results conclude the importance of incorporating the sense of smell in surgical simulators. Further, multimodal interaction can benefit any training simulations by making them more realistic and provide more natural experience similar to that in real life.

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