Robot with an Olfactory Display: Decorating its Movements by Smells

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***Abstract*— This study explored olfactory displays for social robots. In particular, we tested decorating robot movements by using smells as a way for nonverbal expression. To this end, two prototype devices which enabled a humanoid robot to present smells during its movements were developed based on the following design requirements: (1) the smell presentation had to be synchronized with the robot movements, (2) the devices could be easily mounted to the robot, (3) the devices could present and switch between multiple smells, and (4) the intensity of the smell presentation was controllable. Initial pilot tests were conducted with human participants.**

I. Introduction

Studies revealed that humans were affected by smell sensation [1], [2], [3]. Olfactory signals are transmitted to the cortex via thalamus, and olfactory bulbs have direct connections to the limbic system, a brain region associated with memory and emotion [4]. In fact, humans use body odors in emotional communication [5].

On the other hand, nonverbal expressions have been widely studied for communication robots, such as facial expressions [6], [7], body expressions [8], LED-based displays [9], and body temperature [10]. However, the use of smells for such robots were unexplored. Considering the physical properties of robots, bodily movements could provide effective expressions with the addition of smells.

In this study, we explored the use of smells as a method for nonverbal communication for robots interacting with humans (Fig. 1). Following previous works concerning olfactory displays [11], [12], [13], we developed two prototype devices which could be attached on existing robots to enhance their nonverbal communication capabilities by using either a commercially available aroma diffuser or a handmade pneumatic device. Pilot tests were conducted to see the feasibility of both the two devices and to obtain knowledge as to the possible improvements of the devices.

II. Basic Requirements

We started our developments based on the following design requirements: (1) the smell presentation had to be synchronized with the robot movements, (2) the devices could be easily mounted to the robot, (3) the devices could present and switch between multiple smells, and (4) the intensity of the smell presentation was controllable.

Concerning (2), we aimed to let users feel that the robot, rather than the device, was presenting smells. The requirement (4) was needed to present smells at an appropriate intensity based on the distance between the robot and the user.

In the following sections, we will explain two prototype devices we developed. Each device was composed of a presentation part for smells and a control part for the whole device.

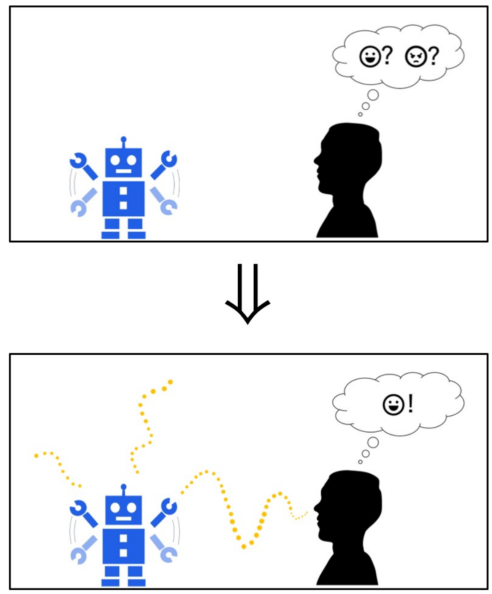

Fig. 1. The use of smells as a way to enhance/modulate robot expressions.

III. Prototype-1

Prototype-1 was developed with the requirements (1) and (2) explained in Section II. A humanoid robot, Pepper produced by SoftBank Robotics Group Co. was used on which the device was mounted (Fig. 2).

A. Hardware Design

The mobile diffuser, Funfan produced by AT-AROMA Co., Ltd. [14] was used as the source of smells. Arduino Uno R3 was used in the control part for operating the device, and Tower Pro SG92R micro servo was used as the actuator of the presentation part. Smell ingredients were diffused by a blower fan (Fig. 3). The weight of the device was 567 g.

Fig. 4 illustrates how the servo motor operates the switch of the mobile diffuser and turns on/off the smell. First, the servo motor pushes the body of the mobile diffuser (① in Fig. 4), and then the mobile diffuser moves toward a case wall (②). The diffuser switch is thus pushed against the wall (③). The diffuser can return to the original position by the reaction force of the push button.

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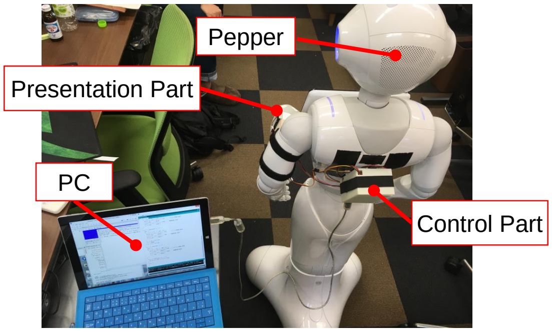

Fig. 2. Overall view of the Prototype-1 mounted on the robot.

Fig. 3. The presentation part.

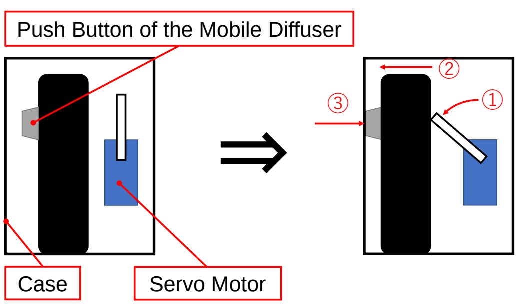

Fig. 4. The mechanism of switching on/off the mobile diffuser.

B. Software Design

We used Python and Arduino IDE 1.8.5 to create programs executed by Arduino. Python 2.7 SDK 2.5.5 Win 32 was used for Pepper. The Python software controlled Pepper and performed serial communications with Arduino on a USB connection so that it controlled Pepper and the device simultaneously.

C. Developmental Result

Prototype-1 was able to present a smell ingredient approximately 30 cm in front of the device in synchronization with the robot's movements. However, since the direction of the presentation part changed according to the movement of the robot, the smell sometimes did not effectively reach the user. Furthermore, with this mechanism, it was difficult to completely seal the diffuser. As a result, after a repeated use of this device, a slight leakage of the smell ingredient was unavoidable.

IV. Prototype-2

Next, Prototype-2 was developed with the all four requirements explained in Section II.

A. Hardware Design

For Prototype-2, we developed a handmade pneumatic device instead of using commercially available aroma diffusers. Fig. 5 shows the overall structure. It delivered smells by passing air through the inside of the tube. A small CO2 gas cylinder (Green Gas 2, the SUN PROJECT Ltd.) which had often been used for pneumatic rubber artificial muscles was used. The CO2 gas cylinder was enough quiet and powerful for our purpose. The selection of the regulator needed with great care and therefore we purchased a reliable set of the CO2 gas cylinder and the regulator. The small proportional control solenoid valve (PVQ31-6G-23-01, SMC [15]) was used for the air flow control. The tube we used was made of urethane, with an outer diameter of 6 mm and an inner diameter of 4 mm. The perfume case was made by a 3D printer. The case contained cotton with aroma oils, and the smell was released from the holes of the tube (Fig. 6). As seen in Fig. 7, we made five holes of about 4 mm in diameter opened at intervals approximately 10 cm from the tip of the tube. To switch between two different smells, two solenoid valves and two perfume cases were prepared. The control circuit of the solenoid valves was shown in Fig. 8.

B. Software Design

The software configuration used for controlling Prototype-2 was the same as used for Prototype-1 (Section III-B).

C. Developmental Result

Prototype-2 was able to diffuse smells approximately 1 m from the robot in synchronization with its movement. Furthermore, by controlling two solenoid valves, two types of smells could be switched. Since we used a tube in the presentation part, the control part could be separated, allowing the robot movement to be less restricted. Prototype-1 suffered from smell leaks even when the device was turned off. However, using a highly airtight solenoid valve in Prototype-2, the perfume case and the tube effectively prevented the perfume from leaking.

V. Pilot Test

A test was conducted to confirm the overall operation of the Prototype-2 device. We also tested if the device could affect human impressions as to robot movements by recruiting six university students in their twenties (five males and one female). The test was approved by the ethical committee of the University of Tsukuba (2019R289) and was conducted based on consent obtained from the participants.

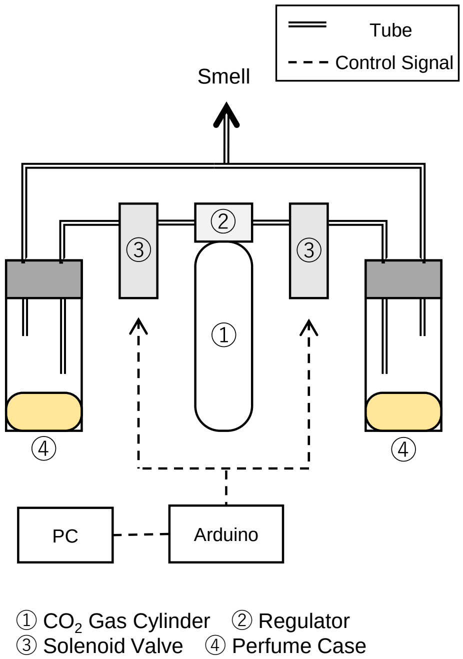

Fig. 5. The structure of Prototype-2.

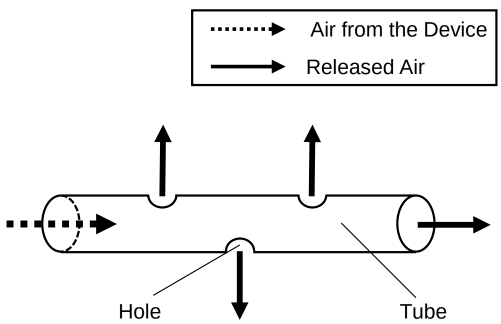

Fig. 6. Perforated tube.

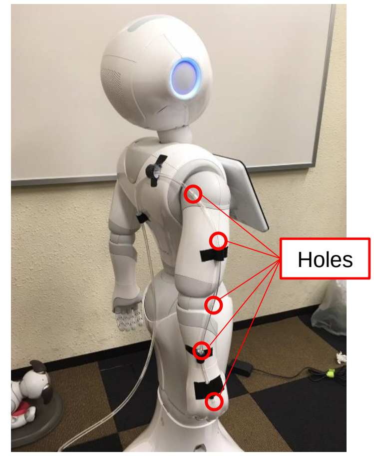

Fig. 7. Hole arrangements.

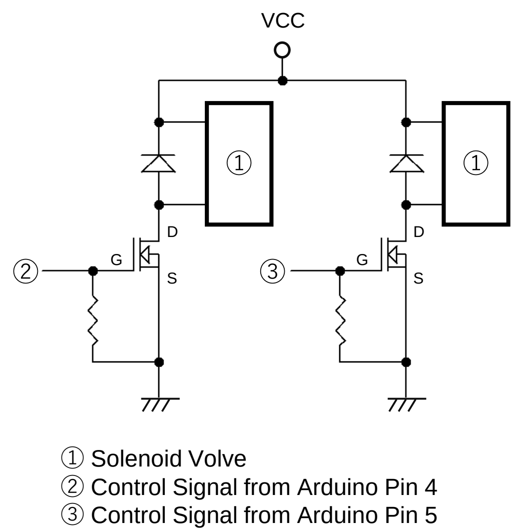

Fig. 8. Control circuit for solenoid valves.

A. *Objective*

We put two different smells (lavender/lemongrass scents) on three different robot movements. Then, we measured the participants' feelings against those movements by using a questionnaire. Through the test, we also wanted to confirm the overall operation of the Prototype-2 device that we developed.

We did not intend to do a formal experiment; however, for a better understanding, we had working hypotheses. Because of the relaxing effect of lavender scents and the arousing effect of lemongrass scents, we hypothesized that the lavender smell would decrease the participants degree of arousal and that the lemongrass smell would increase it. Moreover, since these two smells were generally preferred by most people, we anticipated that these smells would make the participants enjoy the robot movements more than the case with no smell. As such, our hypotheses could be summarized as follows:

- Hypothesis-1: The lavender smell will increase the "relaxed" impression for each movement.
- Hypothesis-2: The lavender smell will decrease the "happy" and "angry" impressions for each movement.
- Hypothesis-3: The lemongrass smell will increase the "happy" impression for each movement.
- Hypothesis-4: The lemongrass smell will decrease the "sad" and "relaxed" impressions for each movement.

B. *Robot Movements*

Three robot movements (Fig. 9) were used for this test:

- Movement-1: Wave the right arm with an opened hand.
- Movement-2: Raise and lower both arms in front of chest with closed hands.
- Movement-3: Raise both arms with opened hands.

Movement-1 was selected as a movement with no emotional meaning. Movement-2 was characterized as an angry emotion, and Movement-3 was chosen as a relaxed emotion.

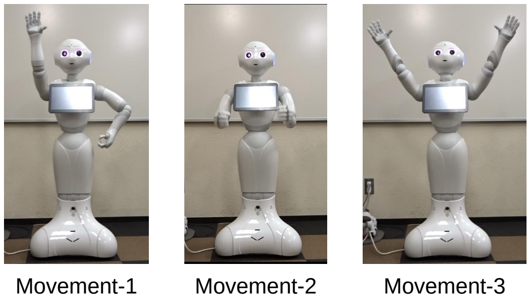

Fig. 9. Three robot movements.

C. Measurement

Participants were asked how each robot movement made them feel by using a questionnaire. They were requested to answer based on a six-point scale of strongly disagree to strongly agree for four emotions (happy, angry, sad, and relaxed) which were representative emotions in each of the four quadrants divided by the two axes of pleasure-displeasure and degree of arousal in the Russell's Circumplex Model [16]. According to this model, "happy" is pleasure and high-arousal, "angry" is displeasure and high-arousal, "sad" is displeasure and low-arousal, and "relaxed" is pleasure and low-arousal.

D. Procedure

Each participant was positioned 0.8 m from the robot. After a basic instruction was given from an experimenter, the participant was presented with a robot movement based on the experimental condition. As soon as the movement ended, the participant was asked to answer to the questionnaire. The procedure was repeated nine times (nine movement/smell combinations) in a random order to each participant (within-participant design). In order to reduce the influence of the smell remaining after presentation, the time for generating the smell was set to 0.5 seconds from the start of the movement, and an interval of about 2 minutes was provided between each condition. During this interval, the participant smelled coffee to refresh their sense of smell. After completing all conditions, the participant was asked to fill out a free-form questionnaire.

E. Results and Discussion

TABLE I summarizes the results of the test. Due to the small number of participants, we did not perform statistical analyses. Therefore, the following discussion has to be interpreted tentatively.

Regarding Hypothesis-1, the value for "relaxed" tended to be consistently higher for the conditions using the lavender smell than the conditions with no smell for each movement. Lavender's relaxing effect might have made the robot movement feel more relaxing to the participants. Regarding Hypotheses 2-4, results were mixed and no consistent trend was observed when comparing the conditions.

For Movement-2, the "happy" impression received higher ratings than the other impressions even in the no smell condition. The movement might not have been well-designed. In conducting the next experiment, manipulation check will surely be needed.

TABLE I

PARTICIPANTS' FEELINGS IN EACH CONDITION (M: THE MEAN VALUE, SD: STANDARD DEVIATION).

Movements	Smell	Happy		Angry		Sad		Relaxed	
		M	SD	M	SD	M	SD	M	SD
Movement-1 (no emotional meaning)	No Smell	2.8	0.9	0.5	0.5	1.3	1.6	1.7	0.9
	Lavender	3.5	1.1	0.8	0.7	0.8	0.9	1.8	1.3
	Lemon-grass	2.7	0.9	0.5	0.5	1.3	1.6	2.2	1.6
Movement-2 (expressing angry)	No Smell	2.5	1.1	2.2	1.3	1.2	1.3	1.0	1.0
	Lavender	1.8	1.5	1.5	1.0	0.8	1.1	1.8	1.8
	Lemon-grass	2.7	1.5	2.3	1.4	0.8	1.5	1.0	1.2
Movement-3 (expressing happy)	No Smell	3.3	1.1	2.0	1.5	0.3	0.5	1.2	1.7
	Lavender	3.7	1.1	1.2	1.1	1.0	1.2	1.8	1.8
	Lemon-grass	3.8	0.9	0.5	0.5	0.5	0.8	2.0	1.9

In the free-form questionnaire, a participant remarked that he/she felt that the strength of the smell was related to the strength of robot's emotions. Investigating the perception of the intensity of a smell with manipulating robot movements is worth to be tested.

The free-form questionnaire contained several suggestions for improving the device design further. For example, a participant noted that at times there was a weak but detectable smell during the condition with no smell. It is possible that this is due to lingering smell ingredients in the tube from when the device was in smell-generation mode. It might be necessary to use different tubes for each smell test to avoid this experimental error. For example, if three distinct smells are used in a particular study, three tubes might be required. In addition, it might be necessary to vent the inside of the device by releasing the contaminated air before the smell-containing presentation is performed.

A participant noted that the smell-generation device made a sound when releasing the smells. Although there was a big improvement about its operation sound in Prototype-2 compared with Prototype-1, still more improvement is needed.

VI. CONCLUSION

In this study, two prototype devices were developed to enable a humanoid robot to present and switch between different smells during its body movements as a form of communication. We conducted a pilot test to see whether the robot equipped with the device could change the impression of humans. Future work will be aimed at improving the device based on the feedback we obtained from these experiments, and testing at longer interaction scenarios than with simple robot movements.

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REFERENCES

[1] A. Rikowski and K. Grammer, "Human body odour, symmetry and attractiveness," Biological Sciences, 266(1422), pp.869-874, 1999.
[2] S. Chu and J.J. Downes, "Proust nose best: Odors are better cues of autobiographical memory," Memory & Cognition, 30(4), pp.511-518, 2002.
[3] Y. Bannai, M. Ishizawa, H. Shigeno, and K. Okada, "A Communication Model of Scents Mediated by Sense-descriptive Adjectives," Advances in Artificial Reality and Tele-Existence, ICAT 2006, Lecture Notes in Computer Science, vol.4282, Springer, pp.1322-1332, 2006.
[4] R.M. Sullivan, D.A. Wilson, N. Ravel, and A.-M. Mouly, "Olfactory memory networks: from emotional learning to social behaviors," Frontiers in Behavioral Neuroscience, 9:36, 2015.
[5] D. Chen and J. Haviland-Jones, "Human Olfactory Communication of Emotion," Perceptual and Motor Skills, 91(3), pp.771-781, 2000.
[6] C. Bartneck, "Interacting with an embodied emotional character," International Conference on Designing Pleasurable Products and Interfaces, pp.55-60, 2003.
[7] C. Breazeal, "Function meets style: Insights from emotion theory applied to HRI," IEEE Transactions on Systems, Man, and Cybernetics, Part C, 34(2), pp.187-194, 2004.
[8] J. Novikova and L. Watts, "A design model of emotional body expressions in non-humanoid robots," International Conference on Human-Agent Interaction, pp.353-360, 2014.
[9] J. Feldmaier, T. Marmat, J. Kuhn, and K. Diepold, "Evaluation of a RGB-LED-based Emotion Display for Affective Agents," arXiv:1612.07303, 2016.
[10] D. Peña and F. Tanaka, "Touch to Feel Me: Designing a Robot for Thermo-Emotional Communication," Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction, pp.207-208, 2018.
[11] J. Amores and P. Maes, "Essence: Olfactory Interfaces for Unconscious Influence of Mood and Cognitive Performance," Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, pp.28-34, 2017.
[12] J. Amores, J. Hernandez, A. Dementyev, X. Wang, and P. Maes, "BioEssence: A Wearable Olfactory Display that Monitors Cardio-respiratory Information to Support Mental Wellbeing," Proceedings of the International Conference of the IEEE Engineering in Medicine and Biology Society, pp.5131-5134, 2018.
[13] K. Hasegawa, L. Qiu, and H. Shinoda, "Midair Ultrasound Fragrance Rendering," IEEE Transactions on Visualization and Computer Graphics, 24(4), pp.1477-1485, 2018.
[14] AT-AROMA Co.,Ltd. https://www.at-aroma.com/en/
[15] SMC Corporation. https://www.smcworld.com/en-jp/
[16] J.A. Russell, "A Circumplex Model of Affect," Journal of Personality and Social Psychology, 39(6), pp.1161-1178, 1980.