Validation of the Design of a Robot to Study the Thermo-Emotional Expression

Denis Peña [1][0000-0002-4220-7339] and Fumihide Tanaka[2] [0000-0002-8443-5591]

University of Tsukuba, Tsukuba 305-8573, Japan
[1]penia@ftl.iit.tsukuba.ac.jp, [2]fumihide.tanaka@gmail.com

Abstract. The thermal sensation can be used by humans to interpret emotions. Hence, a series of questions arise as to whether the robot can express its emotional state through the temperature of its body. Therefore, in this study, we carry out the design process of a robot and its validation as a platform to study the thermo-emotional expression. The designed robot can vary the temperature of its skin between 10-55°C. In this range, it is possible to perform thermal stimuli already studied that have an emotional interpretation, and also to study new ones where the pain receptors are activated. The robot's shape is designed to look like the body of a creature that is neither human nor animal. In addition, it was designed in such a way that the physical interaction occurs mainly in its head. This is because it was decided to locate the robot's thermal system there. The results of an experiment with a free interaction showed that the main regions to be caressed were the superior, lateral and upper diagonal faces of the cranium. These regions coincide with the location of the robot's thermal system. Therefore, the robot can transmit different thermal stimuli to the human when a physical interaction occurs. Consequently, the designed robot will be appropriate to study the body temperature of the robot as a medium to express its emotional state.

Keywords: thermal emotional expression, robot skin temperature, physical HRI.

1 Introduction

Emotional expressions are important for social robots to improve their interaction with humans. Its implementation is inspired by human emotional expression. The emotional expressions conventionally used by robots are facial expressions, body movements, and tone of voice. These three modalities are perceived by the human sense of sight or hearing. However, there are almost no modalities that stimulate the other human senses like the sense of touch. Moreover, taking into account that humans express their emotions through various modalities [1], we believe that a robot with more variety of emotional expressions may improve the naturalness of its interaction. Therefore, we attempt to investigate an unconventional robotic emotional expression: the temperature.

The thermal stimulus is selected for three main reasons. Firstly, it is measured constantly. The human being is sensing all the time thermal stimulus about the temperature of his environment, the objects he is touching and even the temperature of his own body. Secondly, the human's body temperature reacts naturally and involuntarily to emotions. For instance, an embarrassed person will feel his emotion reflected in the involuntary increase of the temperature of his face. Even though this change in temperature could be minimal in other emotional states, L. Nummenmma et al. [2] revealed the human perception about the body sensation associated with different emotions through maps. In each of these maps, it is possible to visualize the activity of body regions that increase or decrease according to an emotional stimulus. Thirdly, humans can give emotional interpretations to thermal sensations [3, 4]. Wilson et al. [3] mapped various thermal stimuli in the circumflex model of emotion. The results provide information on how thermal stimuli can convey to emotions. Thus, humans can use thermal sensation as a medium not only to get information but also to interpret emotions [5].

There are few studies on the effect of temperature during an interaction between a human and a social robot [6, 7]. For instance, Nie et al. [6] suggest that a warmth temperature in a robot's hand increase the human perception of friendship toward a robot; while Park and Lee [7] exposed that different levels of the robot's skin temperature affect the human perception of the robot as a companion. However, as far as previous research is concerned, there is no investigation of how a social robot can use its body temperature to express its emotional state.

As mentioned previously, humans express their emotion states through various modalities. While the change of temperature in the body is an involuntary reaction, facial expressions and body movements can be voluntaries expression [8]. Thus, pseudo-emotions might be expressed by them. That is the case when people control, for instance, their facial expression in order to hide their real feeling. Bearing this in mind, the ultimate aims of this project are: (1) Analyze the change of the robot's body temperature by itself as a medium to express the robot's emotions. Then, with the thermal stimuli that have a strong emotional interpretation, we plant to (2) Analyze the effects of combining thermal stimulus, an unconventional and involuntary emotional expression, with facial expression, traditional and voluntary expression. The combination will be made in two conditions: (a) Both expressing the same emotion; and (b) both expressing different emotions. In the first case, we expect to have a stronger multimodal emotional interpretation. In the second case, we expect to generate a confusing emotional interpretation. For instance, have the feeling that the robot is actually sad, based on the emotional interpretation of its body temperature, even though it has a happy face.

To address these research questions, the main features of a suitable robot should be the capability of varying the temperature of its skin above or below the ambient temperature, as well as the ability to perform facial expressions. Because there is no robot platform that can fulfill these features, the objective of this work is to validate the design process of a robot to adequately investigate the thermo-emotional expression.

2 Anatomical Background

The human body is characterized by a thermoregulation process. This consist of maintaining an almost constant core internal temperature around 37°C. In addition, human beings can detect "gradations of cold and heat, from freezing cold to cold to cool to indifferent to warm to hot to burning hot" [9] (Fig. 1). The body obtains this information through thermoreceptors. There are at least three types, those receptors for pain, those for warm stimuli, and those for cold stimuli. Each of them generate different sensation. The activation temperature range of each thermoreceptor is presented in the Fig. 1.

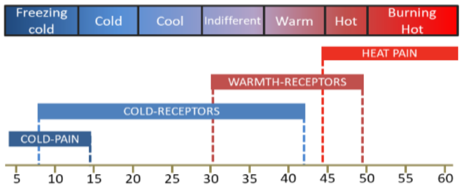

Fig. 1. Temperature range of activation for each thermoreceptor. Graphic based on [9]

3 Features of Thermal Stimuli as Robotic Emotional Medium

3.1 Universal

Human being can perceive thermal stimuli through thermoreceptors. Moreover, the sensation among humans is similar, regardless of gender, age or any other social status.

3.2 Unaltered Shape

To provide temperature to the skin of the robot, it is not required to modify its shape. Therefore, a robot can communicate thermal sensation without changing its shape.

3.3 Privacy

Feature pointed out by Lee [5]. A thermal stimulus can be perceived only by the person who interacts with the robot without anybody else knowing.

3.4 Non Disturbing

It does not disturb any person who does not physically interact with the robot.

4 General Design Decision for the Robot

4.1 Shape of the Robot

Two main factors were considered to decide the shape of the robot. First, the benefits of the robot's shape for a physical interaction with its body. This is desirable because the change of the robot's body temperature will be felt through a physical contact. When analyzing the physical interaction in the human-human case, we believe that this depends to a large extent on the type of relationship that exists between them. Even then, this is usually reduced to the greeting process. In contrast, we think that the physical interaction with a pet (caresses and touching) can extend in duration and frequency. Thus, a pet shape could be more suitable than a human shape for our research interest. The second factor was the benefits of the robot's shape to make facial expressions. In this aspect, a human face has a good versatility compared to the face of a pet. A shape of a creature can converge the benefits of each shape. This is because its shape can be designed to invoke the body of an unreal animal and, at the same time, can make several evident facial expressions without losing its naturalness. Therefore, it is decided to design the shape of the robot as that of an unreal creature.

4.2 Thermal System

It is desired that the robot can vary its skin temperature in such a way that it can convey emotions. However, there is no defined temperature range as the most appropriate to express emotions. Previous works have explored different temperatures within the range of 17.9-39.5°C [3, 4]. In this range, only the cold and warm receptors are activated, but not the pain receptors. However, based on Fig.1, the temperature range between 10-55°C covers the stimulation of all human thermoreceptors. This range includes the temperatures already studied and, at the same time, also allows the study of thermal stimuli where the pain receptors are activated. Thus, this range was selected as a requirement for the skin of the robot.

R1*: The skin of the robot must reach temperatures from 10°C to 55°C.*

Among the thermal systems, the thermoelectric module (TE) can generate both heat and cold. This is achieved by controlling the polarity of the DC power applied along with an adequate heat dissipation system. In addition, the TE has no movable parts, is compact and economical. Based on its benefits, the TE is selected as the robot's thermal system. However, it is not flexible and its shape is usually a flat rectangle. Therefore, the surfaces of the robot where the TE will be placed will be limited to flat surfaces.

4.3 Location of the thermal System

Since the use of TE will restrict the design of the robot's external surfaces to flat surfaces, it is desirable to locate the thermal system only in the area of the robot most likely to be caressed. As mentioned previously, the selected shape of the robot is of a creature. For this shape, we speculate that its head could react to caresses better than other parts of its body. Therefore, we seek to design the robot in such a way that the main area to caress it is its head. Additionally, to reduce the possibility that other parts of the robot could be caressed, the upper and lower extremities are removed.

H1*: The head will be the area of the robot most likely to be caressed or touched.*

5 Structure of the Robot's Body

The structure of the robot's body is divided into three main sections: head, neck, and body base (see Fig.2b).

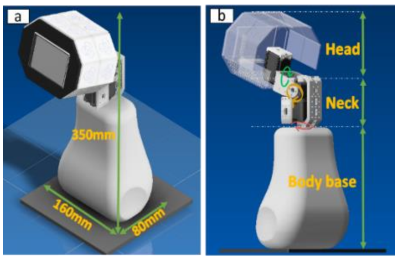

Fig. 2. (a) Isometric view and (b) sections of the robot's body and the 3 DoF on the neck [10]

5.1 Head

Two sub-sections are distinguished: the face and the cranium. In the case of the robot's face, it consists of a screen and a cover. The screen is part of a smartphone and it is used to visualize different facial expressions; while the cover is used to prevent the human from associating the robot's face with a mere smartphone's screen. On the other hand, the cranium stands out for being the only area of the robot that has the ability to modify the temperature of its skin, although limited to the 5 surfaces indicated by a red color in Fig. 3c. This is because the thermal system is located here. It is integrated by a set of thermoelectric units (TEUs) and heatsinks. There is a total of 12 TEUs distributed in two rows of 6 units. They are placed on the superior, upper diagonal and lateral faces of the cranium (Fig. 3c). The heat generated by the TEUs is dissipated by a piece of heatsink under each TEU. These pieces are obtained by cutting a heatsink LAM4 by Fisher Electronik. The heatsink originally is a square bar.

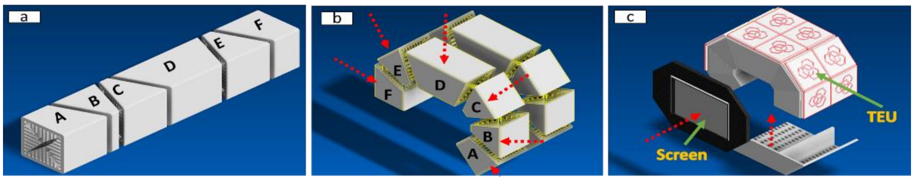

Fig. 3. (a) The heat sink LAM4 by Fisher Electronik are cut into pieces. Then, (b) these pieces are assembled to form the head structure. Finally, (c) the TEUs and the screen are added. [10]

5.2 Neck

This section stands out for allowing the mechanical movement of the head in different orientations during interaction with a human. The neck's mechanism has in total 3 DoF, where each join has a Dynamixel AX-12+ servo (see Fig. 2b).

5.3 Body Base

It is composed of pieces fabricated with a 3D printer. Its aesthetical function is to provide the robot with a morphology of a creature, whereas its structural functions are to support the robot's head and contain electronic components.

6 Validation of the Designed Robot

6.1 About the Thermal System

It was evaluated the temperature range of the robot's thermal system. Thus, a test was performed to (1) determine the minimum achievable temperature, and (2) determine if the thermal system can achieve 55°C. It is not calculated the maximum reachable temperature because, taking into account **R1**, it is more relevant to verify that the thermal system can reach 55°C. The current system has not incorporated its own temperature sensor; therefore, it uses an open-loop temperature control. The test was done in an ambient temperature of 22°C. It was applied 9V to an individual TEU 5 times. The average of the temperature measured on the side of the TEU that has no contact with the heatsink is shown in Table 1. Based on these results, it is verified that the thermal system can achieve the temperature range of 10-55°C in an ambient temperature of 22°C. Thus, the robot satisfies the requirement **R1**.

Table 1. Average temperature range of a TEU placed on the robot's thermal system

	Voltage (V)	Current (A)	Temperature (° C)	Time (s)
(1) Min. temperature	9	1.6	>68	3.3
(2) Reach 55°C	9	2.2	8.9	5.5

6.2 About the Location of the Thermal System

An experiment was carried out to identify by regions the degree of intention to caress the robot's body. This experiment was approved by the ethical committee of the University of Tsukuba (IRB number: 2017R166-1). We expect that the location of the thermal system is contained or coincides in the regions with the greatest intention of caressing. Night right-handed participants without a physical disability were recruited (age: M= 25.89, SD=6.05; 66.7% male).

Before the experiment, a preparation session was carried out. In this, the participant was instructed to interact freely with the robot. In other words, the participant could talk, ask, touch, caress, or do any other activity with the robot. It was also explained that the robot will react according to its capabilities, although no details were given about which they are. The experiment had no time limit and ended once the participant indicated it. After the explanation, the participant was taken to sit on the sofa in front of the robot to begin the experiment (Fig. 4a).

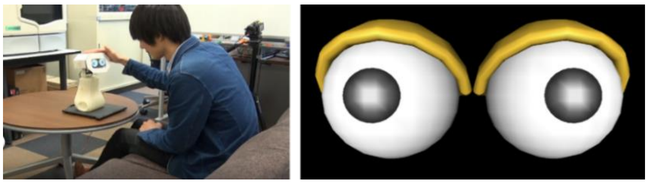

Fig. 4. (a) Experimental setup. The participant is sitting on a sofa facing the robot. (b) The face of the robot. The movement of the iris is controllable.

During the experiment, the robot was capable of activating the mechanical system located in its neck in order to move its head. In addition, on the robot's face, two eyes were displayed with an iris capable of moving around the sclera (see Fig 4b). The movement of the neck and the iris were controlled using the Wizard of Oz (WoZ) technique. Although the robot had the TEUs installed in its cranium, the thermal system was not utilized in the experiment. In addition, the robot did not express any sound.

At the end of the experiment, a survey composed of a questionnaire and two colorable maps was carried out. In the questionnaire, the participant was asked about the appearance of the robot; which areas he touched or caressed and which ones did not. Six areas were established: cranium; face; neck; upper, middle and lower part of the body. The experimenter inquired about the reasons behind each answer. As for the colorable maps (see Fig 5a), they were used to know more precisely where the participant will touch the robot. Thus, the body of the robot was divided into 33 zones (See Fig 5b). Each map is colored according to a 10-steps linear color bar. In the first colorable map, the participant was explicitly asked to indicate the degree of intention to touch or caress the robot, whereas in the second map the intention of no-touch or no-caress the robot.

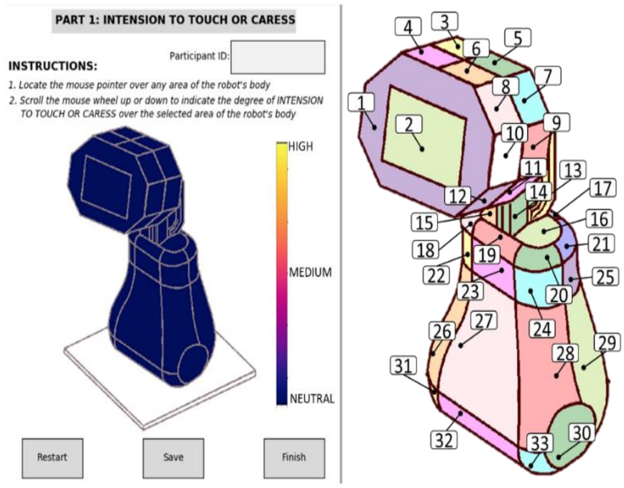

Fig. 5. (a) Colorable map for the degree of intention to touch or caress. There was a similar map for the degree of intention to no-touch. (b) Enumeration of the 33 zones in which the body of the robot is divided.

The results of the questionnaire showed that all participant tend to consider the shape of the robot like not a real animal, but a living creature. Each of them touched the robot at least 4 times. In addition, 100% answered that they will touch or caress the cranium, 44.4% the face, 0% the neck, 66.7% the upper part of the body, 77.8% the middle part of the body, 66.7% the lower part of the body. Moreover, when they were asked for the main part of the robot they will caress or touch, 100% said the cranium. The noted reasons were that they felt a logic reaction of the robot as well as it was natural for them to touch the head like in the case of a pet. About the main part of the robot they will no-touch or no-caress, 77.8% said the neck because it seems unsafe to touch it, whereas

22.2% indicate the lower part of the body because it was unaffordable or the area was associated with an intimate private zone of the robot.

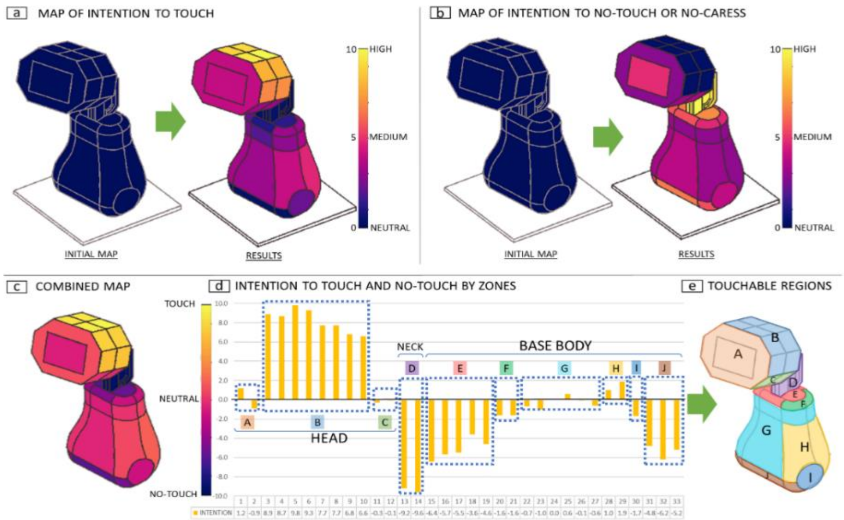

Fig. 6. (a) Results of the map of intention of “touch” or “cares” and (b) the map of the intention of “no-touch” or “no-caress” (c) are combined on a single map. (d)Through an analysis by zones, (e) the body of the robot can be divided into regions according to the intention to touch.

On the other hand, the average result of the colorable maps for intention to touch or caress is shown in Fig 6a, whereas the one for intention to no-touch is in 6b. Because each map shows half of the total scale of intention to touch/no-touch, they are combined into a single map (See Fig 6c). In this map, if a zone has a negative value of intention to be touched, it does not mean that the zone is not touched by the human, but it means that in average the zone tends to be no-touch. Thus, it is possible to visualize that the most touchable zones are located in the head. In the case of the most no-touchable zones, there are on the neck. Moreover, a further analysis by zones was made (See Fig. 6d). The objective was to group neighboring zones with the similar intention to touch into regions. Thereby, it is possible to identify 3 regions in the head: A, B C. Region A alludes to the robot’s face and has an almost neutral intention to touch. In this, although the cover has a slightly positive intention value, the robot’s screen has a slightly negative value. In the case of region B, this is the one with the greatest intention to be touched (on average 7.52 points out of 10). It comprises the superior, upper diagonal and lateral faces of the cranium. Then, region C refer to the lower lateral face of the cranium and it has a low intention to no-touch. Probably, in this regions the lower face of the cranium is also included; however, this is not possible to verify with the robot view shown on the maps. On the other hand, the neck is composed only by the region D. This clearly has the greatest intention of no-touch. Finally, the base body of the robot can be divided into 7 regions. Among them, the region H is the only one that is composed of zones with a positive value to intention to touch. Taking this result into account, this region could be considered a potential area to locate also a thermal system, nevertheless, its degree is considerably lower compared to that of region B. In the next place, region G, although it has a large area, has an almost neutral value. Then, region F, the second nearest neighbor D, and I, the only concave region, have a low degree of intention to no-touch. Finally, region E, the nearest neighbor to region D in the neck, and J, the lowest area of the robot, have the greatest intention of no-touch.

Based on the results, region B (superior, upper diagonal and lateral faces of the cranium) had the greatest intention to be touched was. This region coincides with the location of the thermal system proposed in Section 4.2. Therefore, these results support our hypothesis **H1**. Even more important, considering that there is no other region with high intention to be touched, it is concluded that it is possible to dispense with locating the thermal system in other areas.

7 Limitation and Future Work

At the present moment, the robot cannot perform facial expressions related to emotions, which is a desirable feature for future works. Regarding the thermal system, it has currently an open loop temperature control. Therefore, setting an accurate temperature is limited. To improve this feature, a closed loop temperate control can be implemented by adding a temperature sensor over the side of the TEU that is not in contact with the heatsink. Solving these limitations, the robot will be optimal for studies on the use of the robot body temperature as a medium to express its emotional state. Then, as mentioned in Section I, we aim to study the robot's body temperature as a robotic emotional expression. For that, we plan to use a basic trapezoidal model to express the thermal stimuli. We expect to find some of them with a strong emotional interpretation. Then, we plan to combine thermal stimulus with facial expression in two conditions. Firstly, both expressing the same emotion. As a consequence, we expect that the emotional interpretation will be stronger. Secondly, both expressing different emotions. We expect to obtain a confusing emotional interpretation since each stimulus will transmit different emotions. In this case, we are interested to know whether people could find this confusing interpretation as if the robot were performing a pseudo-emotion. If that is that case, analyze whether people will tend to trust more in one of this stimulus. For instance, have the feeling that the robot is actually sad, based on the emotional interpretation of its body temperature, even though it has a happy face.

8 Conclusion

In this paper, we have described the design process of a robot to study thermo-emotional expression. This robot aims to express its emotional state by changing the temperature of its body. An experiment was conducted to evaluate its design. Firstly, it was verified that the robot's thermal system can achieve temperatures between 10-55°C. This range was set as a requirement to study the thermo-emotional expression because it covers the stimulation of all human thermoreceptors. This range not only includes the temperatures already studied, but also allows the study of thermal stimuli where the pain receptors are activated. Secondly, it was decided to locate the thermal system only in the most potential area of the robot to be touched or caressed. Having set the shape of the robot as that of a creature, the robot was designed in such a way that the people tend to caress mainly the robot's head. Through a questionnaire and colorable maps, it was showed that the mainly regions to be caressed were the superior, lateral and upper diagonal faces of the cranium. These regions are coincident with the location of the thermal system of the robot. Moreover, it was concluded that it is possible to dispense with locating the thermal system in other areas because the other regions of the robot's body have low intention to be caress. In summary, the robot presented in this study is suitable to investigate the robot body temperature as a medium to express its emotional state. This is because, when a physical interaction occurs, the robot can transmit a thermal stimulus to the human.

9 Acknowledgment

This work is supported by KAKENHI 17K19993. A special thanks to Kosmech workshop of the University of Tsukuba for the support in the manufacture of the robot.

References

1. C. Darwin. The expression of the emotions in man and animals. University of Chicago press, vol. 526 (1965)
2. L. Nummenmaa, E. Glerean, R. Hari, J. K. Hietanen. Bodily maps of emotions. Proceedings of the National Academy of Sciences, 111(2), 646-651. (2014)
3. Graham Wilson, Dobromir Dobrev, and Stephen A. Brewster. Hot Under the Collar: Mapping Thermal Feedback to Dimensional Models of Emotion. CHI Conference on Human Factors in Computing Systems. ACM, New York, NY, USA, 4838-4849 (2016).
4. Katri Salminen, Veikko Surakka, Jukka Raisamo, Jani Lylykangas, Roope Raisamo, Kalle Makela and Teemu Ahnaniemi. Cold or hot? How thermal stimuli are related to human emotional system? Proceedings of International Workshop on Haptic and Audio Interaction Design 7989: 20–29 (2013).
5. Wonjun Lee and Youn-Kyung Lim. Explorative research on the heat as an expression medium: Focused on interpersonal communication. Personal and Ubiquitous Computing 16,8: 1039-1049 (2012)
6. J. Nie, M. Park, A. L. Marin and S. S. Sundar. Can you hold my hand? Physical warmth in human-robot interaction. 7th ACM/IEEE International Conference on Human-Robot Interaction, pp. 201-202 (2012).
7. Park, E., and Lee, J. I am a warm robot: The effects of temperature in physical human–robot interaction. Robotica 32(1), 133-142 (2014).
8. Marjorie Fink Vargas. Louder than words: An introduction to nonverbal communication. Iowa State University Press (1986).
9. Guyton AC, Hall JE. Textbook of Medical Physiology (13th ed.). Philadelphia, PA: Elsevier Saunders (2011).
10. Denis Peña and Fumihide Tanaka. Touch to Feel Me: Designing a Robot for Thermo-Emotional Communication. 13th ACM/IEEE International Conference on Human-Robot Interaction (HRI '18). ACM, New York, NY, USA, 207-208 (2018).