Design of Human-Robot Communication and Body-Emotion Model Based on Physiological Phenomena Related to the Robot's Life

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論題

Design of Human-Robot Communication and Body-Emotion Model Based on Physiological Phenomena Related to the Robot’s Life

生命維持(セイメイイジ)にかかわる生理現象(セイリゲンショウ)を介(カイ)した人間(ニンゲン)–ロボットのコミュニケーションと身体情動(シンタイジョウドウ)モデルの設計(セッケイ)

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Abstract

In this dissertation, we focus on physiological phenomena of robots as the expressive modality of their inner states and discuss the effectiveness of a robot expressing physiological phenomena, which are indispensable for living. We designed a body-emotion model showing the relationship between a) emotion as the inner state of the robot and b) physiological phenomena as physical changes, and we discuss the communication between humans and robots through involuntary physiological expression based on the model.

In recent years, various robots for use in mental health care and communication support in medical/nursing care have been developed. The purpose of these systems is to enable communication between a robot and patients by an active approach of the robot through sound and body movement. In contrast to conventional approaches, our research is based on involuntary emotional expression through physiological phenomena of the robot. Physiological phenomena including breathing, heartbeat, and body temperature are essential functions for life activities, and these are closely related to the inner state of humans because physiological phenomena are caused by the emotional reaction of the limbic system transmitted via the autonomic nervous system. In human-robot communication through physical contact, we consider that physiological phenomena are one of the most important nonverbal modalities of the inner state as involuntary expressions.

First, we focused on the robots' expression of physiological phenomena, proposed the body-emotion model (BEM), which concerns the relationship between the inner state of robots and their involuntary physical reactions. We proposed a stuffed-toy robot system: BREAR—which has a mechanical structure to express the breathing, heartbeat, temperature and bodily movement. The result of experiment showed that a heartbeat, breathing and body temperature can express the robot's living state and that the breathing speed is highly related to the robot's emotion of arousal. We reviewed the experimental results and emotional generation mechanisms and discussed the design of the robot based on BEM. Based on our verification results, we determined that the design of the BEM-which involves the perception of the external situation, the matching with the memory, the change of the autonomic nervous parameter and the representation of the physiological phenomena—that is based on the relationship between the autonomic nervous system and emotional arousal is effective.

Second, we discussed indirect communication between humans and robots through physiological phenomena—which consist of the breathing, heartbeats and body temperature—that express robots' emotions. We set a situation with joint attention from the robot and user on emotional content and evaluated whether both the user's emotional response to the content and the user's impression of relationship between the user and the robot were changed by the physiological expressions of the robot. The results suggest that the physiological expression of the robot makes the user's own emotions in the experience more excited or suppressed and that the robot's expression increases impressions of closeness and sensitivity.

Last, we discussed the future perspective of human-robot communication by physiological phenomena. Regarding the representation of the robots' sense of life, it is thought that the user's recognition that the robot is alive improves not only the moral effect on the understanding of the finiteness of life but also the attachment to the robot in long-term communication. Regarding the emotional expression mechanism based on life, it is expected that the robot can display a complicated internal state close to that of humans by combining intentionally expressed emotions and involuntary emotional expressions. If a robot can express a combination of realistic voluntary expressions, such as facial expressions and body movements, in combination with real involuntary expressions by using the real intentions and lying, it can be said that the robot has a more complicated internal state than that of a pet. By using a robot expressing a living state through physiological phenomena, it can be expected that the effect of mental care will exceed that of animal therapy, and we expect to provide care and welfare support in place of human beings.

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Chapter 1

Introduction

1.1 Background

Humans are social animals and live by constantly forming relationships with others and relying on each other. We also build social groups by exchanging information with each other and sharing work. In our social groups, we engage in communication using various expressive modalities in order to build relationships and cooperate with others.

On the other hand, individual humans have an inner state that is an instinctive mechanism for crisis avoidance and survival, and feelings and desires are generated based on this. Through communication with others, the expression of one's inner state is adjusted based on the interests of participants and both parties.

However, artifacts do not have such inner states and consciousness that enable cooperation with others. Also, some studies raising these problems are ignored by design based on biological instinctive mechanisms. It is an important problem that must be discussed to design a robot that is an artificial machine that can communicate with human beings.

At the same time, in recent years, various kinds of robots, such as for commercial and research purposes, have been developed. For example, there are robots that have roles as home appliances or small and lovely decorations, as well as large robots that support humans and robots that look like animals. In addition, there are robots that reproduce human appearance and complex movements in detail, heal human beings through appearance and movements like animals, and communicate with humans by expressing various emotions [1, 2].

In order to realize communication between these robots and humans, it is necessary to develop various representational designs and inner state designs of robots to convey the state and intention of the robots themselves to human beings. Regarding the representation of robots, various studies are being conducted to explore nonverbal expressions such as body movements and facial expressions, utterance contents, and utterance methods. At the same time, multimodal representation by combining these expressions attracts attention.

Regarding the design of the inner state, research is being conducted on human emotion recognition, emotion generation of the robot based on it, and emotional expression. It is expected that these robots will be utilized in various situations in medical care, nursing care, education, and the daily life of humans by using these communication means and expression modalities.

However, it is questionable whether these anthropomorphic systems actually have enough elements to actually build relationships with others. We discuss the necessary factors for robots to become close human companions in the long term.

1.2 Motivation

Anthropomorphic robots are being required to play a role as a substitute for humans. In nursing care and medical care, it is necessary for human beings to respond to communication with patients and children, and the shortage of human resources due to the declining birth rate and aging population in recent years is a serious problem. As a solution, communication support using a robot is expected. It is said that robots are able to contact users as if they are human beings due to their anthropomorphic characteristics of being able to talk and consult with humans. Based on this, robots are expected to be utilized in various situations, such as communication support for dementia patients and mental care of the elderly. For example, pet robot systems for use in mental health care have been developed. This is called "robot therapy," and it replaces pet therapy; it is said that people cope with a variety of physical and mental health issues by touching animals [3, 4, 5, 6]. This is a measure to increase affinity for communication with humans from the viewpoint of a human interface for healthcare support using information technology (it is called networked interaction therapy [7, 8]). In this approach, a animal-like stuffed-toy robot is used, and it is designed to build a close relationship between the user and the robot and to improve attachment to the robot.

In this dissertation, we discuss the factors necessary for a robot to become a long-term, close human partner. If household robots become popular, long-term relationships in daily life will occur. Among them, scenes where children live with pet robots can also be considered. It is also necessary to discuss the influence of robots on children and how to ensure long hours of communication between humans and robots. For example, the necessity of learning about life is being discussed, weighed against animal cruelty toward pets. When pet robots replace animal pets, there are concerns as to how to educate children about their lives.

In this way, next-generation robots are assumed not to unilaterally assist users but to become close partners by enriching emotions while building relationships with humans through communication. In addition, it is important that the user recognizes the robot as a living being. Therefore, we discuss a method for users to recognize robots as living creatures like real pets and discuss whether users and robots can communicate with each other and build close relationships.

1.3 Problems

When reconsidering warm and realistic communication between human beings and pets, we proposed that what is necessary for the robot is an expression based on the living mechanisms indispensable for living existence, not enhancement of superficial moving functions.

Previous research focused on rich utterance content, fluent conversation, realistic appearance and facial expressions, and complex body movements as elements that make the robot feel like a living being. It is said that it is possible for humans to infer the intention of a robot and induce communication through these methods. These studies are attempts to make human beings recognize that “the robot is alive” and try to infer the inner state of the robot through the complexity of the robot’s body movement imitating a living organism and its reality. This theory is that the robot can appear to be alive because it is possible to make its movements resemble those of an animal, which can be regarded as a voluntary expression of life through the voluntary motion of the robot. However, unless the robot intentionally carries out these expressions, humans may not recognize the robot as being a living thing, and they may feel that the robot is alive.

We expect the user to feel that the robot is not an artificial machine but a living thing when the robot directly expresses physiological phenomena indispensable to life. In contrast to expressing the “living” state of the robot through the representation of the physiological phenomena of the robot, the state of being "dead" may be expressed because there are no physiological phenomena indispensable for life support.

Furthermore, physiological phenomena are closely related to the inner state of human emotions [9, 10, 11, 12]. For example, stresses and emotions with high arousal such as fear and surprise cause physiological reactions such as an increased heart rate, perspiration, and accelerated breathing through autonomic nerves and the endocrine system [13, 14]. On the other hand, physiological phenomena may be markedly changed even when an abnormality occurs in the physical condition, such as an abnormality of disease or cardiopulmonary function. Physiological phenomena are indispensable functions for maintaining life and possibly representing the human inner state.

In other words, physiological phenomena are involuntary expressions of the robot, and they represent the state of life and of emotion. In contrast, bodily movements, facial expressions [15, 16], and voice are "voluntary expressions" because these are done based on intentions or can be suppressed. It is expected that the robot will be able to express the delicate nuances of its intention through a combination of two types of expression. We need to investigate combinations of other physiological phenomena, as we estimate robots' emotions comprehensively based on facial expressions and voice. Therefore, it is necessary to construct emotional expressions through physiological phenomena and to clarify their effects.

In the future, if it is possible to express the life and death of the robot, it can be expected to be useful for learning about life in educational institutions and environments in which it is difficult to keep pets.

1.4 Outline of the Proposed Method

We focus our attention on respiration, heart rate, and body temperature, which have important roles for living, and we aim for the expression of the robot's living based on the physiological phenomena of the robot and the expression of the inner state of the robot based on the states of living and death.

In this article, we define the "living" and "dead" states that the user feels from the robot as the "sense of living." In addition, we define the emotions and state of living of the robot that the user feels from the physiological phenomena as the "the sense that the robot is alive."

We try to express multimodal physiological phenomena by combining multiple physiological phenomena and designing the emotion expression model corresponding to the physiological mechanism. We clarify the relationship between physiological phenomena and the inner state of the robot and propose a body-emotion model of the relationship between the inner state of the robot and physiological phenomena. Also, we evaluate the influence of the emotional expression of the robot using the body-emotion model on the user's emotion, and we propose indirect communication between humans and robots as emotional communication through involuntary physiological phenomena in daily life.

First, we design a stuffed robot that expresses breathing, which is a combination of abdominal exercise, sighing, heart rate, and body temperature. We evaluate (1) whether the user feels like the robot is a living thing, (2) whether the user can feel the living or dead states, and (3) whether physiological phenomena influence factors related to the life of the robot and parameters that express what kind of internal state exists.

Next, we design a body-emotion model showing the relationship between the inner state and the physiological phenomena.

Finally, as an application study of the emotional expression of a robot based on a body emotion model, we evaluate whether the empathy between the user and the robot based on the robot's physiological emotional expression affects the relationship-building between the user and the robot and the impression of the robot. We define indirect communication as a situation in which intentional communication is not conducted and emotional interaction is caused by involuntary physiological phenomena. We verify how indirect communication between the user and robot affects (1) the relationship between the user and robot and (2) how the user's emotion toward his or her subjective experiences are changed.

1.5 Outline of this Dissertation

The structure of this dissertation is as follows (see Figure 1.1).

The effects of physiological emotional expression of the robot on the relationship between user and robot and user's emotion in subjective experiences.

Chapter 2 reviews some of the fundamental research contributing to robots' expression of physiological phenomena and related research applications.

Chapter 3 focuses on basic mechanisms of physiological phenomena, describes the body-emotion model of the robot, and evaluates expression of the sense of living and inner state of a robot by focusing on breath as one of the physiological phenomena.

Chapter 4 proposes the indirect communication through the physiological phenomena of the robot as the application and evaluates the effects of the physiological emotional expression of the robot on the relationship between the user and the robot and the user's emotions in subjective experiences.

Chapter 5 describes the consideration of the effect of the robot's physiological expression based on the body-emotion model of human-robot interaction.

Finally, Chapter 6 concludes this dissertation and proposes future work.

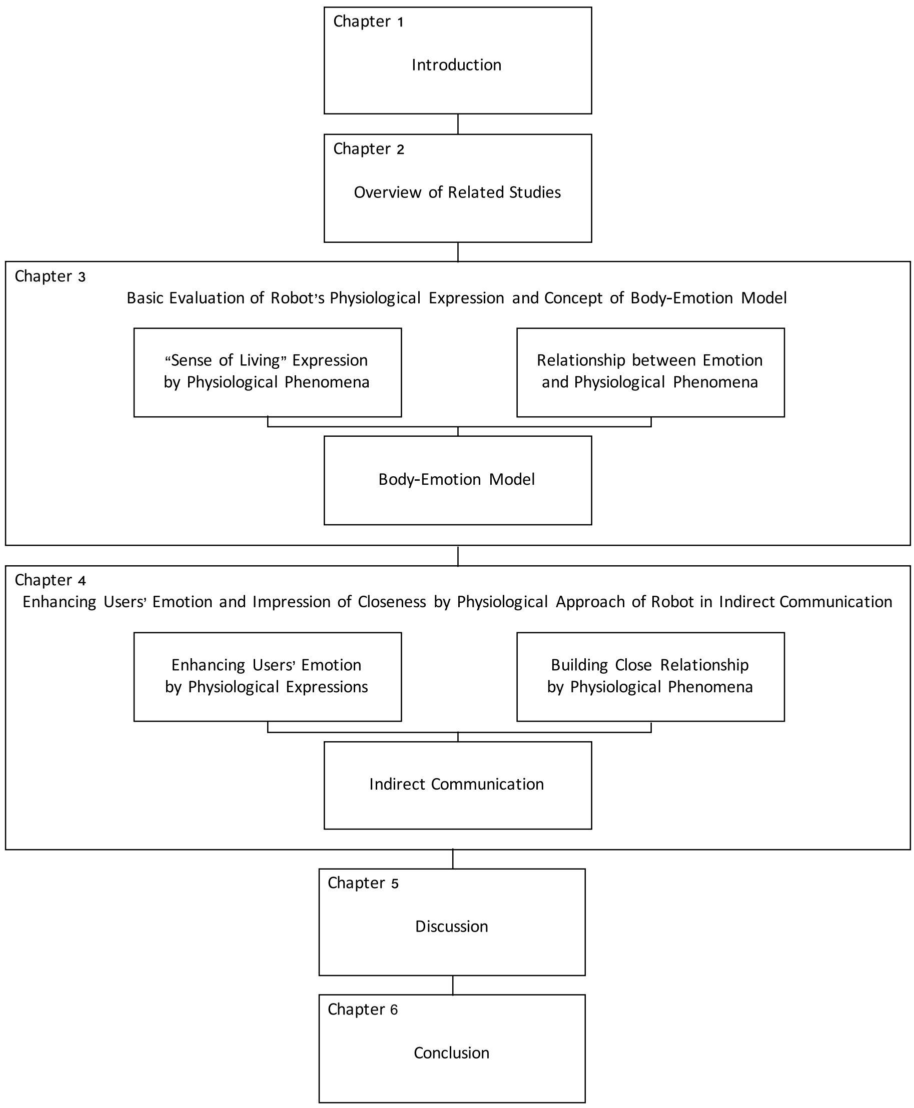


Figure 1.1: Outline of this dissertation

Chapter 2

Overview of Related Studies

This chapter reviews some of the fundamental research contributing to the expression of physiological phenomena of robots and related research applications.

2.1 Modality of Emotional Expression of Robots

One of the characteristics of robots is having a body in the real world [17]. Robots convey intentions to humans through various expressions, making use of this body.

In recent years, various types of robots have been developed with various forms and sizes that are suitable for various uses and scenes, such as communication, guidance, sleeping, or outings [1, 2].

Regarding the representation of robots, various studies are being conducted on nonverbal expressions such as body movements and facial expressions, utterance contents, and utterance methods. At the same time, multimodal representation by combining these expressions attracts attention.

As for a robot's utterance, aside from expressing emotion directly through words, it can show emotion through voice tone or speed. Some researchers have shown that a robot's bodily movements can express various feelings [3, 16, 18]. Some robots show emotions using facial expressions. Some robots have complicated mechanisms of expression [19, 20]. On the other hand, many robots can express emotion by combining body motion and face movements through limited mechanisms such as eyes and mouths [21, 22]. In addition, various emotional expressions combining gaze and conversation have been studied [23, 24].

For these expressions, many models linking robots' emotions and expressions have been proposed. As for involuntary expressions, some researchers evaluated the expression of robots' feelings through physiological phenomena [25, 26]. In their study, emotional expression of robots that imitates animals through multimodal expression by combining body motion and sound and indirect and pseudo breathing through abdominal movement was attempted. In our research, we try to express multimodal physiological phenomena by combining multiple physiological phenomena, and we design the emotion expression model corresponding to the physiological mechanism.

2.2 Physiological Phenomena

Expressions of thoughts and intentions are either voluntarily performed or involuntarily shown. Involuntary reactions include reflex movements and gradual changes through neurotransmitters.

A nonverbal expression consists of both voluntary and involuntary physiological expressions [27]. These include gazing, bodily movement, and intentional facial expressions as voluntary expressions; there are also physiological phenomena, such as one's heartbeat, temperature, sweat, and unconscious breathing, which are involuntary expressions.

The inner state of a human can be understood not only through voluntary expressions but also through certain physiological phenomena [9, 10, 11, 12]. Voluntary expressions are sometimes different than expressions brought on by physiological phenomena. Lying is a typical example [27, 28]. People can express pseudo emotions through voluntary expressions such as facial expressions and body motions. However, certain physiological phenomena are caused by an immediate change in one's autonomic nervous system, if such a person has not been trained.

Physiological phenomena of humans, such as breath, heartbeat, and body temperature, are closely related to emotional states [9, 10, 11, 12]. Physiological phenomena cannot be controlled by people; in other words, physiological expressions of emotion are "involuntary expressions." In contrast, bodily movements, facial expressions [15, 16], and voice are "voluntary expressions" because these are done based on intentions or can be suppressed. It is expected that the robot will be able to express the delicate nuances of its intention through a combination of two types of expression. We need to investigate combinations of other physiological phenomena because we estimate robots' emotions comprehensively based on facial expressions and voice.

We presume physiological phenomena to be important nonverbal media, even when used alone. Emotions and feelings should be discussed separately, and each mechanism in the robot's expressions should be examined as with human beings. We expect that the robot can express delicate nuances of its intention, such as with a real intention or a lie, by distinguishing external emotions from definite feelings.

2.3 Sense of Living of Robots

The behavior of the robot makes the robot appear to be a living being. As a result, it is possible for humans to infer the intention of the robot and induce communication.

For example, about 50% of 106 infants aged 5 to 6 years answered that an AIBO [29] robot who performed various movements was "alive" [30]. The animal-like behavior of Parobo used for "robot therapy" was designed based on the theory that human beings subjectively interpret the behavior of robots [31]. There have been attempts to express the existence of a living being through the robot performing various nonverbal expressions normally performed by humans, such as gaze behaviors and unconscious gestures [32].

It is assumed that by imitating the movements of living animals and humans, robots are recognized as living beings by humans. However, in order for human beings to interpret robots as being alive, it is necessary for the robots to positively take action and for human beings to pay attention to those actions. It is necessary to express the sense of living of the robot through the basic mechanism of life without making it difficult for the user.

The purpose of this research is for the user to recognize and interact with the robot as a living thing rather than an artificial machine by the robot directly expressing physiological phenomena as basic life activity.

2.4 Sense of Closeness

One of the aims of this research is to build a close relationship such as a pet, family, or lover by contact through physiological phenomena in communication between a user and a robot.

Mumm et al. [33] showed the possibility that the distance between humans and robots affects the behaviors and impression of likability between the user and the robot. Thus, there is the possibility that the distance between the robot and the user is a large factor affecting familiarity. Some researchers state that physical contact with robots has a positive effect on the users [34, 35]. Nie et al. [36] showed that physical warmth of the hand and handholding increase feelings of friendship and trust toward the robot through a common experience between the robot and the user. These studies suggest the possibility of building a relationship between a user and a robot based on biological information.

It is said that a robot's body motion and emotional expression make the user feel close to the robot. Janssen et al. [37] referred to the affective communication using the information of the user's heartbeat. This study suggested the possibility of affective communication based on biological information. We also expect emotional exchanges between users and robots based on physiological expression of robots.

2.5 Empathy and Emotional Enhancement

One of the purposes of this research is to elevate the user's emotional experience through emotional expression by physiological expressions of a partner robot in the user's daily life.

One of the important factors in medical and nursing care recently has been arousing the emotions of patients [38, 39]. Some studies have suggested that empathy with partner robots enhances the strength of patients' own emotions [40, 41]. It is assumed that the user's emotional experience is enhanced through the empathetic physiological expressions of the robot.

Related to the enhancement of users' emotions, there is research using robots' bodily movements [42, 43]. In our study, we focused on physiological expression as involuntary expression, verifying whether physiological expression has the same effect as bodily movements.

Some studies have shown that direct manipulation and false feedback of a user's heartbeat with visual and auditory expressions changed the user's emotional or physiological state [44, 45]. In this research, we expected that users' emotions could be enhanced through tactile stimulation from the robot as the third person, while considering the influence on content. Tactile stimulation of the robot's physiological phenomena was expected to produce ambient stimulation to the user in a common context.

2.6 Appearance of a Living-being-like Robot

We adopted an animal-like stuffed toy as the robot's appearance in order to remove the influence of facial or linguistic expressions. It is considered that the animal-like stuffed-toy robot without such complex expressions can still show delicate emotion through our proposed method.

Furthermore, the stuffed robot is expected to be used in medical and nursing care fields like Parobo robots [46, 47] for the purpose of patients' mental therapy, and we expect that rich emotional exchanges with patients and therapeutic effects are realized by adding emotional expression mechanisms through physiological phenomena to these robots.

2.7 Summary

This chapter introduced related studies of the expression modality of robots and the possibility of expression of physiological phenomena as realistic biological expressions.

Robots that have a body in the real world can express artificial emotion through body movements, facial expressions, and utterance contents as voluntary expressions. On the other hand, involuntary expressions are suggested to become a robot's emotional expression modality. Also, the physiological phenomenon itself is expected to enhance the closeness with others, and some studies suggest the possibility of affective communication based on biological information.

The purpose of this research is for the user to recognize and interact with the robot as a living thing rather than an artificial machine by the robot directly expressing physiological phenomena as basic life activity.

Our aims in this research are to enable close relationships to be built, such as a pet, family member, or lover, by contact through physiological phenomena in communication between a user and a robot. We also expect emotional exchanges between users and robots based on the physiological expressions of robots.

The next chapter focuses on basic mechanisms of physiological phenomena, describes the body-emotion model of the robot, and evaluates expression of a sense of living and the inner state of a robot by focusing on breath as one of the physiological phenomena.

Chapter 3

Basic Evaluation of Robot's Physiological Expression and Concept of Body-Emotion Model

Abstract

In this chapter, we focus on physiological phenomena expression of robots, propose the Body-Emotion Model (BEM), which concerns the relationship between the inner states of robots and their involuntary physical reactions. We expect that the robot will be able to express the delicate nuances of its intention by controlling robots' emotions and feelings with each individual parameter based on BEM. We propose a stuffed-toy robot system, BREAR, which has a mechanical structure to express breathing, heartbeating, temperature, and bodily movement. The breathing mechanism commonly controls the abdominal motion, breathing motion, and air flows of breath.

First, we focus on robot's breathing, verify two subjective evaluations: 1) the user's sense that the robot was alive and 2) the perceived states of the robot based on its breathing speed. The results showed that our proposed method of breathing expression can show a state of living and that the breathing speed was interpreted as the robot's emotion of arousal.

Second, we focus on other emotional factors of the robot's physiological phenomena; heartbeat and body temperature, and we discuss relationship between biomechanism and emotion based on factor analysis and analysis based on standardized factor scores in conjunction with experiment of

breathing.

Last, we discuss about emotional expression design of robot based on biomechanism in BEM.

3.1 Introduction

3.1.1 The Relationship between Involuntary Expression and Feeling

There are many non-verbal expressions. A non-verbal expression consists of both voluntary and involuntary expressions as physiological expressions [27]. These include gazing, a bodily movement and intentional facial expression as a voluntary expression; there are also physiological phenomena, such as one's heartbeat, temperature, sweat, and unconscious breathing, as involuntary expressions.

The inner state of a human can be understood not only by voluntary expressions, but also by certain physiological phenomena [9, 10, 11, 12]. Voluntary expressions are sometimes different than an expression brought on by physiological phenomena. Lying is a typical example [27, 28]. People can express pseudo emotions through voluntary expressions such as facial expressions and body motions. However, certain physiological phenomena are caused by the immediate change in one's autonomic nervous system, if such a person has not been trained.

We presume physiological phenomena to be important non-verbal media, even in single use. Emotions and feelings should be discussed separately, and each mechanism in the robot's expressions should be examined as with human beings. We expect that the robot can express delicate nuances of its intention, such as with a real intention or a lie, by distinguishing external emotions from definite feelings.

3.1.2 Basic Concept of Body-Emotion Model for Human-Robot Communication

We propose the Body-Emotion Model (BEM) (see Figure 3.1), which concerns the relationship between the inner states of robots and their involuntary physical reactions.

'Emotion' and 'feeling' in this figure are named from the theory by Damasio [48]. 'Emotion' regards the unconscious activity of the peripheral nervous system, and 'feeling' concerns the function of the frontal association area; that becomes our continuous psychological condition.

Our BEM of the robot's physiological expression was based on the Damasio's theory about perception, emotion, and feelings[48].

First, emotion changes one's physical state as a reaction to various stimuli from one's actions, such as looking, listening, touching, and imagining, by perceiving a phenomenon to a user's body and the surrounding conditions of that user. Second, physiological reactions appear to be based on emotion. Finally, humans become aware of one's feelings by noticing changes in one's physical state, and humans express their own feelings through voluntary and/or verbal expressions.

We expect that the robot will be able to express the delicate nuances of its intention by controlling robots' emotions and feelings with each individual parameter based on BEM.

Some researchers have shown that the robot's bodily movements can express various feelings [3, 16]. As for involuntary expressions, some researches evaluated expression of robots' feelings including physiological phenomena [25, 26]. However, these expressions are not designed models which decide each of voluntary expression based on feelings and involuntary expression based on emotion. We therefore aim to clarify the emotional expression of the robot by only physiological phenomena in BEM.

Physiological phenomena are the physical activities that are indispensable for life support. We also evaluate the expression of a living being-like presence in the robot by expressing the physiological phenomena of the robot.

3.1.3 Verifying Using The BREAR System

We propose a stuffed-toy robot system, BREAR, which has a mechanical structure to express breathing, heartbeating, temperature, and bodily movement. The breathing mechanism commonly controls the abdominal motion, breathing motion, and air flows of breath. The robot system can express both voluntary motions and physiological ventilation as involuntary expressions.

We adopted an animal-like stuffed toy as the robot's appearance in order to remove the influence of facial or linguistic expressions. It is considered that the animal-like stuffed-toy robot without such complex expressions still can show the delicate emotion by our proposed method. Furthermore, the proposed system would be applicable for a robot therapy, which is mental therapy using a stuffed-toy robot[46], using emotional expression with physiological phenomena based on BEM.

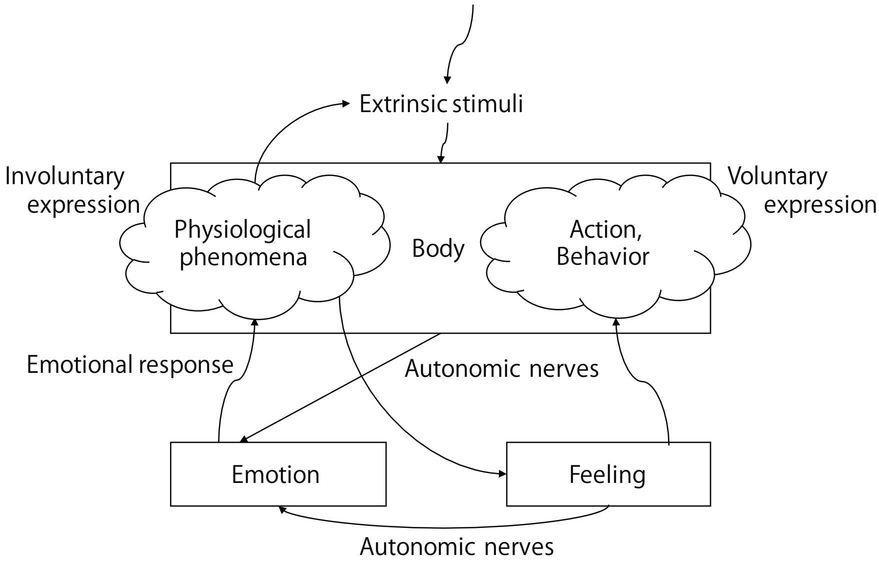


Figure 3.1: Body-emotion model

3.1.4 Breathing of Robot

We focused on the breathing expression among various physiological expressions. Breathing is an important physiological phenomenon that is absolutely necessary for our lives. The stop of the breathing means the death. The breathing-like expression is expected to show as though the robot were alive.

3.2 Related Researches

The research using Parobo[3, 47] showed the possibility of expressions of various feelings of Parobo from non-verbal expressions. However, this research did not consider the physiological phenomena of robots, even though non-verbal expression contains involuntary expressions.

Sefidgar et al. and Yohanan et al. [25, 26] designed a robot that had abdominal motions (without sighing) like respiration, motion of the ears, and a purr box, and they verified the impression of robot feelings.

Yanaka et.al [49] developed a huggable pillow using an animal-like toy with abdominal movement, sleeping breath sounds, and heat like body temperature for sleep deprivation.

Figure 3.2: Appearance of stuffed toy robot

Since feelings and emotion of robots have not been distinguished in these researches, it is difficult to parameterise robots' emotions. Consequently, it is difficult to produce robots' physiological phenomena based on the mapped emotion.

Related to robot's breath, Solis et.al [50] developed the robot which plays a flute. The flute-playing robot has been designed to mechanically reproduce the human organs such as lungs and a throat. Differently from that, our purpose of the breathing expression is focusing on mental cares and the system is implemented with a small stuffed toy robot. The structure of the trachea should be simplified by the limitation of the size, however the flexible chest of the stuffed-toy robot can go up and down. From the structure of simplified but affective design, the user can feel the breathing not only watching but also touching it, and the breathing expression of the robot is more closer if the user hold it.

3.3 Expression of Robot's breathing

3.3.1 Structure of The Stuffed-toy Robot

BREAR (see Figure 3.2) is a stuffed-toy robot about 25 [cm] height, covered with a bear-like toy, enclosing breathing mechanism with as a prototype of some physiologic phenomena; a mechanical structure to express breathing, heart beats, and bodily temperature.

Figure 3.3 shows the internal structure robot. The device for breathing expressions is composed of a 250[mL] balloon imitating a lung, an air pump (DC6[V] 230[mA], 2[L]/[min], 400[mmH]) and a solenoid valve (DC6[V] 90[mA]) with a pressure sensor that detects amount of air in the lung. The bodily temperature of the robot is expressed by a film heater (DC12[V] 5[Ω]) around the armpits to the back, and the heart beats of robot are expressed by a vibration motor (DC5[V], 3000–4800[rpm]) at the chest. Tactile inputs from the user are detected by three piezo sensors (DC3[V] 1[MΩ], minimum sensitivity 20–100[g]) placed at he tip of the arms and top of the head. A small speaker (8[Ω] 0.5[W]) in the robot makes its voice. Seven servo motors (DC5[V], 2.2[kgf/cm], 0.11[sec]/60 °) are placed to the head (two D.O.F), each arm, each leg, and the backbone of the robot for bodily movements. A speaker is enclosed in the head of the robots. These devices are controlled by an AVR microcomputer (Arduino UNO R3, ATmega328P, 16[MHz]). These devices are connected to the PC through the microcomputer except the speaker directly connected to the PC.

3.3.2 Control of The Breathing

The robot's breathing is expressed in two steps. Figure 3.4 and 3.5 show the details of each step.

1 When the amount of air in the lungs is less than a lower threshold, the air pump works and the solenoid valve closes at the same time in order to accumulate the air in the lungs.

2 When the air in the lung exceeds an upper threshold, the air pump stops and the solenoid valve opens at the same time in order to discharge the air from the mouth of the robot.

Breathing speed is controlled by changing threshold value of maximum lung air pressure.

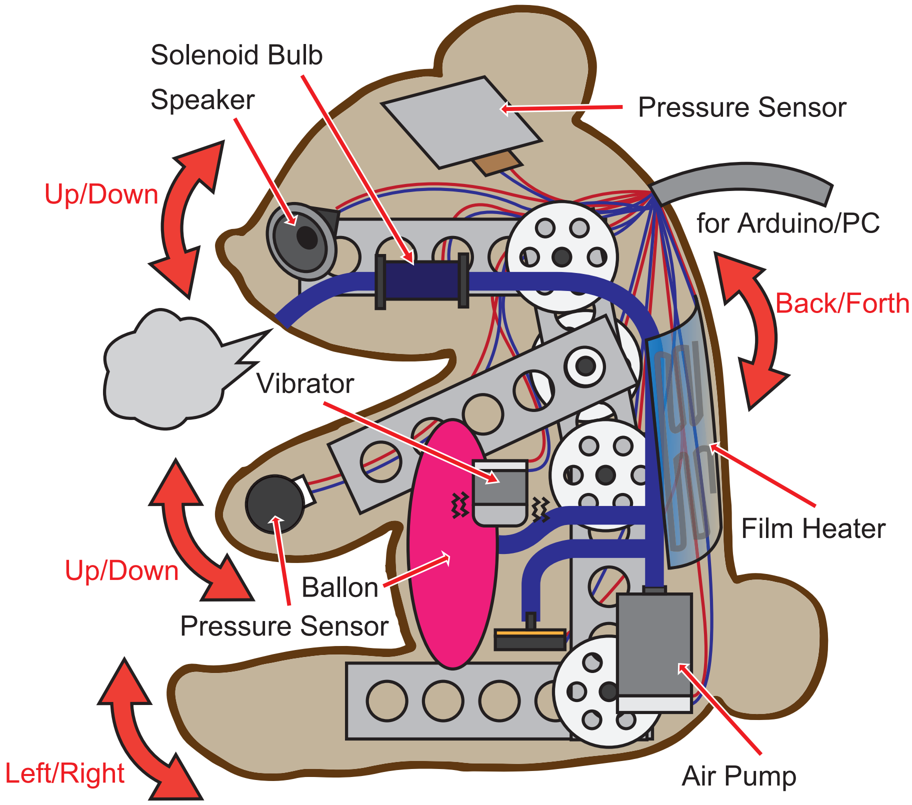


Figure 3.3: Structure of stuffed toy robot

3.4 Experiment 1: Expression of Sense of Living and Emotion by Robot's Breathing

3.4.1 Overview of Experiments

In this experiment, we verified two subjective evaluations focusing on robot's breathing. A breathing contains multiple elements such as a sound of sigh, exhaled air and abdominal movements, and these elements cannot be separated from the breathing mechanism. The breathing mechanism in our proposed system has a unified structure of their controls, so we treat the mechanism as an unseparated unit.

First, we verify whether the sense of a living being can be perceived from the robot's breathing. Second, we clarify the emotional map of the

(a) Inhaling

(b) Exhaling

Figure 3.4: Sigh of BREAR

user perceived from the robot's breathing by factorial analysis.

3.4.2 Living State by Robot's Breathing and Robot's Life

Purpose of Experiment: We verified the effectiveness of the breathing speed to express the robot's inner state especially living state.
Hypothesis: The participants recognize the breath as though the robot were living. The strongest feeling of living state is observed when the breathing speed of the robot becomes close to the general speed of human breath.
Participants: 26 university students aged from 19 years old to 22 years old (16 males and 10 females).
Conditions: The six types of breathing speeds.

- c0 0 times per minute (without breathing),
- c1 3 times per minute (very slow),
- c2 9–10 times per minute (slow),
- c3 16–19 times per minute (medium),
- c4 23–25 times per minute (fast) and
- c5 56–60 times per minute (very fast).

Procedures and Instructions: First, the participants were told that this experiment is a performance evaluation of the robot. Next, the participants were lectured on how to hold the robot close to their face (20 [cm]). The participants observed the robot during 20-second experiments and answered

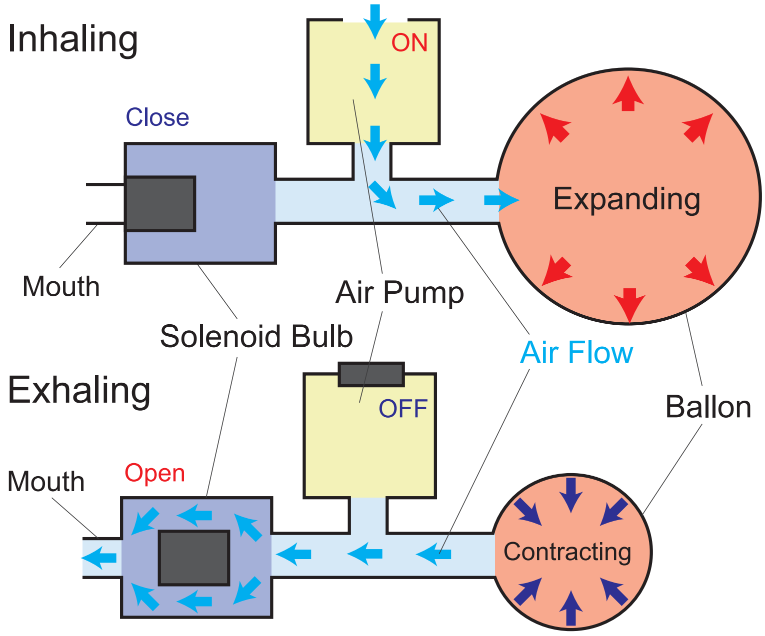


Figure 3.5: Air flow with breathing

the evaluation items after each session. The six conditions were repeated measurement with counter balanced.
Evaluation Items: Evaluation Items: The participants made an evaluation using a five-point scale rating of the relevance (5: very relevant, 4: somewhat relevant, 3: even, 2: somewhat irrelevant, 1: irrelevant) of the following statements.

Q1 This robot seems like a living being,

Q2 This robot seems not like a living being,

Q3 This robot seems alive,

Q4 This robot seems dead and

Q5 This robot seems about to die.

Result: Figure 3.6 shows the results of means opinion scores (MOS) for each statement (significance level: ** $p<.05$). In the results from Q1 to Q4,there were significances between c0 and c1–c5, that are the difference of with or without breath. These results showed that the robot's breathing expressions are able to show the aliveness of the robot regardless of the speed of the breath. The results for Q5 also showed significances between c0 and c4 and between c0 and c5. It is conjectured that the speed of the robot's breath changed the participants's recognitions of detailed inner state of the robot. Accordingly, we tried to verify the relationship between impressions for inner states of robots and the speed of the breath in the next experiment.

3.4.3 Relationship of Impression for inner state and Breathing

Purpose of Experiment: We tried to verify the relationship between the impression for inner state of the robot and the speed of the breath.
Participants: 26 university students aged from 19 years old to 22 years old (16 males and 10 females).
Conditions: Two conditions of different speed of the robot's breathing.

c11 9–10 times per minute (slow) and

c12 23–25 times per minute (fast).

Procedures and Instructions: Same as procedures and instructions in the previous experiment.
Evaluation Items: The impressions for the robot were evaluated by using the semantic differential (SD) method. Participants answered the evaluation items of 23 adjective pairs (in Japanese) related to perception, physiology, and personality as shown in Table 3.1 in the left line.
Extraction of Factors: Factor analysis was performed on the results of SD method ratings for the 23 adjective pairs. According to the difference in eigen values by a major-factor method, we adopted two factors while the cumulative contribution ratio was 57.7%. The factor matrix was rotated by a Varimax method (shown in Table 3.1). The first factor was named "Lively" factor and the second one was named "Pleasant" factor from the factor loadings.
Hypothesis for two-factor analysis: Two independent hypotheses as follows were investigated: 1) The speed of breath expresses the Lively emotion of the robot and 2) The speed of breath expresses the Pleasant emotion of the robot.
Comparison of Factors by the Breathing Speed: Standardized factor scores were calculated by a standardized partial regression coefficient. Table 3.2 shows the result of ANOVA (analysis of variance) for each standardized factor score in order to compare the conditions. The result showed a significant

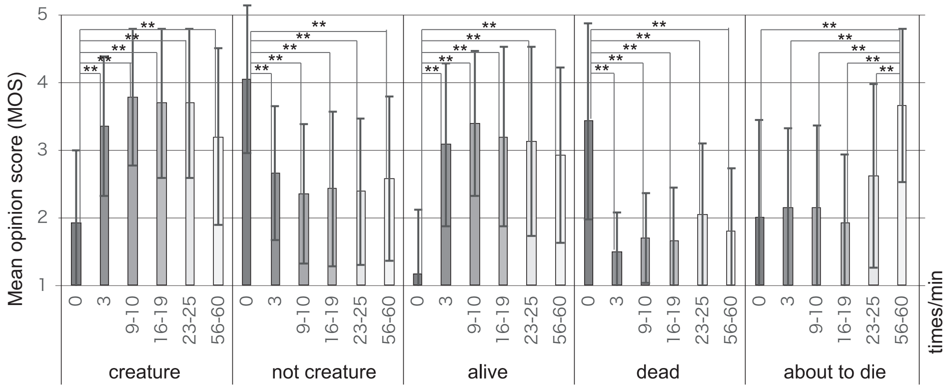


Figure 3.6: Results of subjective evauation.

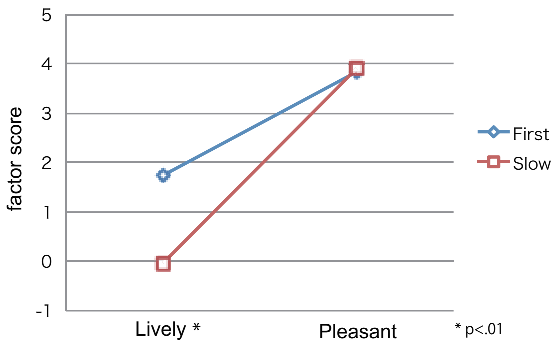


Figure 3.7: Comparison of factor scores

difference between two conditions of breathing speed in the Lively scores (see Figure 3.7). In contrast, there was no significance in the Pleasant scores.

3.4.4 Discussions

Relations of Robot's Breathing and Robot's Life

First, we discuss the positive impressions for the user's feeling that the robot was alive. From the results of the experiment, it is conjectured that the robot's breath expressed the robot's living state compared to the robot without breath. That is to say, there was no significance among breathing expressions with different speeds and with the limited range of the speed of the robot's breath.

Table 3.1: Factor pattern of the SD ratings and standardized factor scores (Varimax normalized)

Adjective pairs	Lively	Pleasant	standardized partial regression coefficient Lively	Pleasant
Light–Dark	0.436	0.501	0.021	0.037
Strong–Feeble	0.575	0.204	0.042	-0.002
Warm–Cold	-0.115	0.513	-0.025	0.048
Positive–Negative	**0.605**	0.487	0.053	0.040
Cheerful–Gloomy	0.422	**0.686**	0.018	0.094
Intence–Mild	**0.894**	-0.008	0.241	-0.109
Pleasant–Unpleasant	0.021	**0.825**	-0.058	0.160
Interesting–Boring	0.143	0.411	-0.003	0.028
Fun–Suffering	0.044	**0.666**	-0.024	0.073
Lively–Feeble	**0.749**	0.457	0.127	0.046
Stable–Unstable	**-0.637**	0.315	-0.085	0.071
Dynamic–Static	**0.846**	0.204	0.167	-0.031
Extroverted–Introverted	0.517	0.583	0.035	0.061
Grad–Sad	0.024	**0.817**	-0.055	0.152
Calm–Restlessly	**-0.837**	0.118	-0.167	0.096
Careful–Hasty	**-0.692**	-0.254	-0.068	0.001
Rational–Emotional	-0.589	0.161	-0.057	0.039
Eager–Languor	**0.607**	0.534	0.057	0.054
Energetic–Tired	0.49	**0.732**	0.034	0.152
Merry–Lonely	0.501	**0.685**	0.038	0.110
Aggressive–Weak	**0.691**	0.191	0.067	-0.009
Happy–Unhappy	-0.189	**0.768**	-0.762	0.141
Substantial–Empty	0.115	**0.757**	-0.029	0.108

In the result of Q3 to Q5, each state of living of the robots was expressed in condition of different breathing speed. The speed of the robot's breath showed the possibility to express a detailed state of living of the robot. On the other hand, the speed of the robot's breath showed a possibility to express detailed inner state of living of the robot as shown in the results for Q5.

Table 3.2: Average and standard deviation of factor scores for Impression of robot's breathing

	Condition	First	Slow
	Participant	26	26
Factor score	Lively	1.736	-0.037
	Pleasant	3.828	3.901
SD	Lively	0.152	0.158
	Pleasant	0.868	1.002

Factor Analyses of Impressions for Breathing

Next, we discuss the results of factor analyses in evaluating two speeds (fast and slow) of breathing.

From the results of factor analyses, there were two factors of the robot's breathing: "Lively" and "Pleasant"; while the speed of the breath only affects the Lively factor. Lively factor seemed to include the adjectives related not only to visual expression of the breathing movement but also to impression of inner state and emotion. These results showed that there is a relationship between living-being-like perception of the robot and the speed of the robot's breath.

Pleasant factor is assumed to be affected by other parameters of breathing expressions except the speed; for example, there are parameters of the breathing expressions such as the strengths of the air flow and the intervals as though the robot holds its breathing. The effects of these parameters should be verified including contexts of human–robot communication in the future.

3.4.5 Lively Factor of Breathing Expression Based on BEM

We considered that two factors, Lively and Pleasant, seem to be tied to a circumplex model[51]. Consequently, we applied the parameter of "Pleasantness" to correspond to the Pleasant factor and the parameter of "Arousal" to correspond to Lively (See Figure 3.8). For instance, the sudden contact from a user produces a surprising state with arousal and causes early breathing, or the kind patting or stroke produces relaxed emotion of the robot and its breath becomes slow down, as the examples shown in Table 3.3.

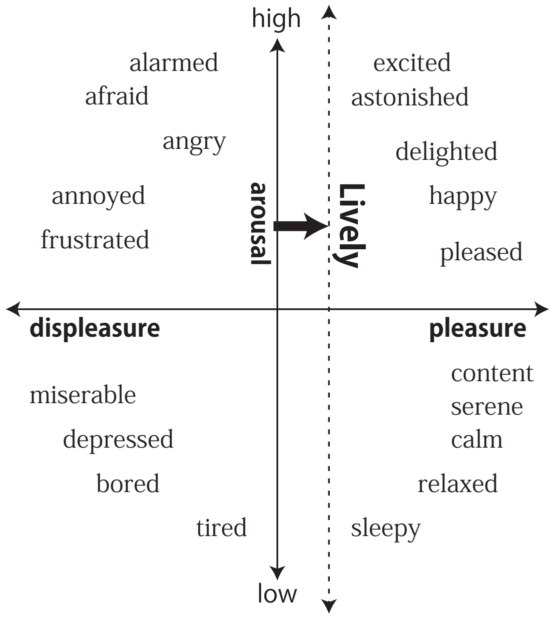


Figure 3.8: Mapping of lively factor based on circumplex model

3.5 Experiment 2: Relationship Between The Emotion and Heartbeat/Body Temperature

3.5.1 Summary

In this experiment, we verified emotional factors of the robot's physiological phenomena (heartbeat and body temperature) through factor analysis and analysis based on standardized factor scores in conjunction with the experiment of breathing.

Table 3.3: Example of robot's breathing based on Lively

Stimulation	Emotion	Lively	Breathing tempo
Clenching the hand suddenly	Surprised	HIGH	FAST
Beating the head suddenly	Surprised	HIGH	FAST
Leave unattended	Boring	LOW	SLOW
Continue touching in long time	Boring	LOW	SLOW
Patting kindly	Relaxing	LOW	SLOW

Table 3.4: Experimental conditions

Heat rate		Body temperature		Breathing	
None	0	None	24	First	9–10
Low	40	Low	30–32	Slow	23–25
Normal	60	Normal	35–37		
High	80	High	39–41		
Very high	110				
	(times/min.)		(deg.)		(times/min.)

3.5.2 Experimental Method

First, we clarified the emotional factors perceived from each physiological phenomenon of the robot through factorial analysis. Second, we analyzed how emotional factors were changed by controlling each physiological phenomenon. These methods were also used for the previous experiment of the robot's breathing. The participants in the experiment involving the robot's heartbeat and body temperature were different from participants in the experiment of breathing. The participants experienced the heartbeat experiment before the body temperature experiment.

Figure 3.4 shows the experimental conditions of breathing, heart rate and body temperature. The order of the conditions was counterbalanced for each physiological phenomenon.

In terms of procedures, first, the participants were instructed that the experiment was a behavioral evaluation of the robot. Next, the participants were lectured on how to hold the robot. They were told that the correct method was by "placing your hand on the robot's stomach and not moving." In each session, the participants observed the robot for 10 seconds before answering. The questionnaire was composed of 23 adjective pairs related to emotion, perception, physiology and personality (shown in figure 3.5), for the SD method (with a 5-point scale rating). The instruction "Please provide the degree of applicability regarding the robot's impression" was written at the top of the questionnaire.

3.5.3 Factor Analysis and Analysis Based on Standardized Factor Scores of Physiological Phenomena

Breathing: Twenty-six university students aged between 19 and 22 years old (16 males and 10 females) participated in the "breathing" experiment. According to the difference in eigenvalues and the cumulative contribution ratio by a major-factor method, we adopted two factors, and the cumulative contribution ratio was 57.7%. The factor matrix was rotated using the Varimax method. The first factor was named "Arousal," and the second was named "Pleasant" from the factor loadings (< 0.6).

Standardized factor scores were calculated using a standardized partial regression coefficient. Figure 3.9 shows the result of ANOVA (analysis of variance) for each standardized factor score in order to compare the conditions (significance level: * $p < .05$). The result showed a significant difference between two conditions of robot's breathing speed in the arousal scores. In contrast, there was no significance in the pleasant scores.

Heartbeat and body temperature: Next, we conducted evaluations of heartbeat and body temperature with 20 university students aged between 19 and 24 years old (11 males and 9 females).

Regarding heartbeat, according to the difference in eigenvalues and the cumulative contribution ratio by a major-factor method, we adopted one factor for which the cumulative contribution ratio was 49.3%. The factor matrix was rotated using the Varimax method in both factor analyses. The factor was called the "representational arousal" factor from the factor loadings (< 0.8). Standardized factor scores were calculated as with breathing, and the result of ANOVA showed that the scores for the faster heart rate condition in the factors of high and very high were significantly higher than the scores for the normal heart rate condition.

For body temperature, we picked up only one factor, where the cumulative contribution ratio was 51.6%. All of the adjective pairs over 0.8 were included in those of analysis of heartbeat. Therefore, the only extracted factor for body temperature was called the "representational arousal factor," as shown in Table 3.5. Standardized factor scores were calculated as with other analyses; the scores of the factor showed significantly high values in high or very high body temperature conditions compared to the values in the low body temperature condition.

3.5.4 Discussion

First, from the results of the factor analyses for each expression of the robot's physiological phenomena, it is considered that both factors of heartbeat and body temperature correspond to arousal emotion of the robot from these results, while the robot's breathing involves two factors: arousal and pleasure. Arousal in particular is affected by the speed of the robot's breathing.

From the result, we assume that the arousal is expressed by all three physiological phenomena: breathing, heartbeat and body temperature. High

Table 3.5: Factor loadings of each factor.

	Heart rate	Body temperature	Breathing Arousal	Breathing Pleasant
Light–Dark	0.780	0.756	0.436	0.501
Strong–Feeble	0.707	0.699	0.575	0.204
Warm–Cold	0.685	0.745	-0.115	0.513
Positive–Negative	0.883	0.833	0.605	0.487
Cheerful–Gloomy	0.843	0.810	0.422	0.686
Intence–Mild	0.415	0.233	0.894	-0.008
Pleasant–Unpleasant	0.615	0.787	0.021	0.825
Interesting–Boring	0.635	0.835	0.143	0.411
Fun–Suffering	0.511	0.705	0.044	0.666
Lively–Feeble	0.843	0.820	0.749	0.457
Stable–Unstable	0.243	0.410	-0.637	0.315
Dynamic–Static	0.702	0.731	0.846	0.204
Extroverted–Introverted	0.784	0.717	0.517	0.583
Grad–Sad	0.857	0.778	0.024	0.817
Calm–Restlessly	0.483	0.360	-0.837	0.118
Careful–Hasty	0.533	0.512	-0.692	-0.254
Rational–Emotional	0.509	0.593	-0.589	0.161
Eager–Languor	0.767	0.808	0.607	0.534
Energetic–Tired	0.799	0.846	0.490	0.732
Merry–Lonely	0.931	0.805	0.501	0.685
Aggressive–Weak	0.770	0.694	0.691	0.191
Happy–Unhappy	0.616	0.793	-0.189	0.768
Substantial–Empty	0.774	0.824	0.115	0.757

respiration rate, high heart rate and high body temperature express high arousal of the robot.

3.6 Body-Emotion Model based on biomechanism

3.1.2 describe concept of BEM. In this section review the experimental results and emotional generation mechanisms and discussed the design of the robot based on BEM.

From the result, we assume that the arousal is expressed by all three physiological phenomena: breathing, heartbeat and body temperature. High respiration rate, high heart rate and high body temperature express high arousal of the robot.

Now, we summarize the relationship between physiological phenomena and emotions in the process of generating of emotions. In the somatic marker hypothesis by Damasio [48, 52], the information obtained from the outside is said to unconsciously evoke a physical change (emotional reaction). The autonomic nervous system activates the cerebral cortex due to external stimuli, and the emotion is generated by the interaction of the emotional circuit (Papez circuit [53]) and the memory circuit (Yakovlev circuit [54]) passing through the thalamus [55]. Figre 3.10 shows the flow of the summarized process. Also, the amygdala acts on the neurotransmitter autonomic nerve and causes a physiological phenomenon as an emotional reaction [9, 10, 11, 12]. This reaction on the activity of autonomic nerves is part of a mechanism to promote crisis avoidance behavior and preparing for fighting in an animal, and it is also expressed as a threatening action in animals[56, 57]. In other words, the expression of autonomic nervous activity, physiological phenomena, generation of emotion is regarded as a linked mechanism, it is considered that the physiological phenomenon expressed through this mechanism leads to recognition of emotions by others.

Considering our verification results, it is suggested that the activity in autonomic nervousness and emotional arousal are related to each other. Because of our verification results, it is suggested that the activity in the autonomic nervous system the and emotional arousal are related to each other, and it is considered that a design of the BEM—which involves the perception of the external situation, the matching with the memory, the change of the autonomic nervous parameter and the representation of the physiological phenomena—is effective.

From these discussions, we designed the inner design of a robot by BEM based on a simplified model of human mechanisms (see Figure 3.11). First, the processor corresponding to the thalamus collates the database stored in the memory corresponding to the memory circuit and the emotion circuit based on the information input from the sensor corresponding to the sensory tissue. Next, the generation unit of physiological phenomenon corresponding to the amygdala outputs the autonomic nervous parameter value indicating the activity level of the autonomic nerve. Based on this value, each physiological expression unit outputs a physiological phenomenon. It is considered that physiological phenomena representation according to the context and surrounding circumstances will be realized by implementing this flow.

3.7 Summary

In this chapter, we focused on physiological phenomena expression of robots, proposed the Body-Emotion Model (BEM), which concerns the relationship between the inner states of robots and their involuntary physical reactions. We proposed a stuffed-toy robot system, BREAR, which has a mechanical structure to express breathing, heartbeating, temperature, and bodily movement. The breathing mechanism commonly controls the abdominal motion, breathing motion, and air flows of breath.

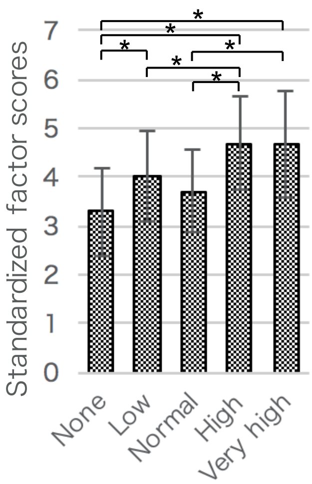
First, we proposed our stuffed-toy robot with breathing expressions which involves the speed to show the robot's different inner states as a living being-like presence. we described the configuration and control for physiological phenomena expression, and proposed breathing expression by common control of abdominal movement and exhalation.

Second, we reviewed the related studies about categorization of emotion and feeling and mechanism of physiological phenomena of human, describe concept of body-emotion Model. In this dissertation, 'Emotion' was defined as unconscious activity of the peripheral nervous system based on theory by Damasio, set the concepts as follow; (1) emotion changes one's physical state as a reaction to various stimuli from one's actions, such as looking, listening, touching, and imagining, by perceiving a phenomenon to a user's body and the surrounding conditions of that user, (2) physiological reactions appear to be based on emotion, (3) humans become aware of one's feelings by noticing changes in one's physical state, and humans express their own feelings through voluntary and/or verbal expressions.

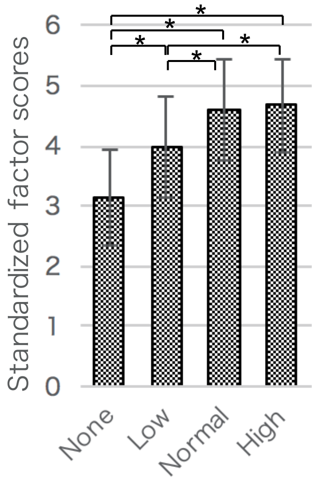
Third, we verified the robot's perceived living state by changing the speed of the breath. The results of the evaluations and factor analyses conjectured that the robot's breathing can express the living state and that the speed of breath is highly related to the robot's emotion of arousal. Also, we verified emotional factors of the robot's physiological phenomena (heartbeat and body temperature) through factor analysis and analysis based on standardized factor scores in conjunction with the experiment of breathing. From the result, we assume that the arousal is expressed by all three physiological phenomena: breathing, heartbeat and body temperature. High respiration rate, high heart rate and high body temperature express high arousal of the robot.

Last, we review the experimental results and emotional generation mechanisms and discuss the design of robot based on BEM. Considering our verification results, it is suggested that the activity in autonomic nervousness and emotional arousal are related to each other, and it is considered that a design of the BEM that involve the perception of the external situation, matching with the memory, the change of the autonomic nervous parameter and the representation of the physiological phenomena is effective. From these discussion, we designed the inner design of robot by BEM based on simplified model of human mechanism.

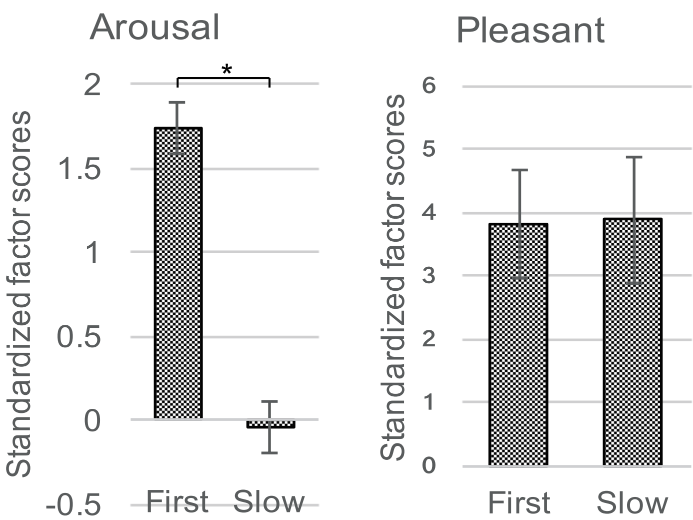
In chapter 3, by expressing the physiological phenomena by changing the parameters based on the model, we propose the indirect communication by physiological phenomena of the robot as the application scene, evaluate the effects of physiological emotional expression of the robot on the relationship between user and robot and user's emotion in subjective experiences.



(a) Heartbeat



(b) Body temperature



(c) Breathing

Figure 3.9: Mean and significance of each standardized factor score

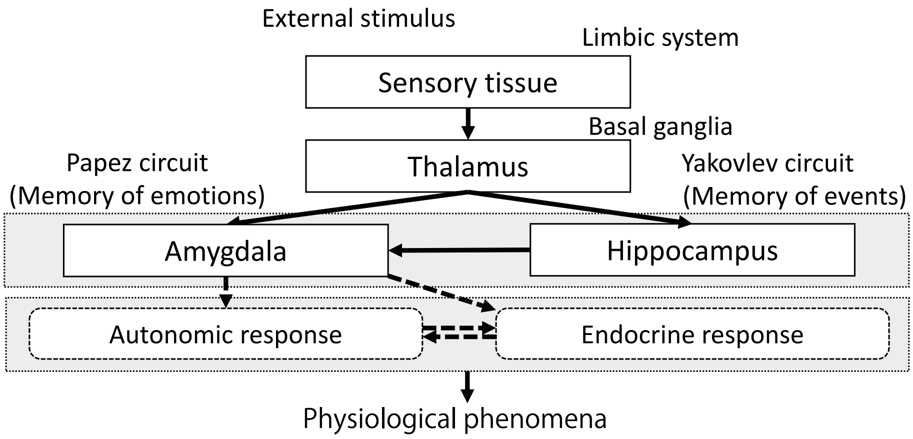


Figure 3.10: Flow of summarized emotional response

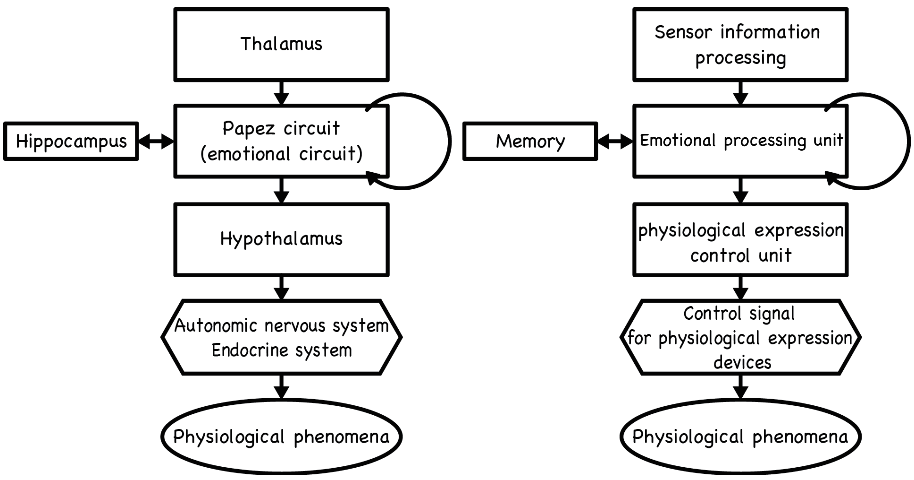


Figure 3.11: Physiological expression flow of robot

Chapter 4

Enhancing Users' Emotion and Impression of Closeness by Physiological Approach of Robot in Indirect Communication

4.1 Introduction

In this paper, we discuss the possibility of an indirect communication between human and robot through physiological phenomena, which consist of breathing, heartbeats and body temperature, expressing the robot's emotion. We set a situation of joint attention between the robot and user to an emotional contents, and evaluated whether both the user's emotional response to the content and the user's impression on relationship between the user and the robot were changed by the physiological expressions of the robot. The results suggest that the physiological expression of the robot would make the user's own emotion in the experience more excited or suppressed, and that the robot's expression would increase impressions of closeness and sensitivity.

4.1.1 Enhanceing User's Emotion by Physiological Emotional Expression of Robot

One of the important factors in medical and nursing care recently has been arousing the emotions of patients [38, 39]. Many types of communication robots and pet robots have been developed as communication partners for patients [3, 47]. Some studies have suggested that empathy with partner robots enhances the strength of one's own emotion [40, 41]. It is assumed that the user's emotional experience is enhanced by empathetic physiological expressions of the robot.

The purpose of this research is to elevate the user's emotional experience through emotional expression by physiological expressions of a partner robot in the user's daily life. The user's emotions are stimulated during direct communication with the robot, although there is less chance that the robot approaches the user in other situations such as watching TV and listening to music without disturbing him or her. The user feels that the robot is troublesome during the user's other tasks. It is possible that ambient but emotional expressions of physiological phenomena are perceived by touch, even when the user concentrates on other tasks. If the enhancement of users' emotions using robots is realized, it is expected to stimulate a patient's emotions on a daily basis by enhancing his or her emotion not only in direct communication with the robot but also through indirect sharing of the emotional experience with the robot, such as mutual attention/emotion.

4.1.2 Building Close Relationships with Robots

In recent years, communication robots have been expected to be utilized in homes and public facilities, and there are discussions of what kind of modality is needed for human-robot communication to establish a familiar relationship. For example, "physicality" and "distance / space arrangement" are mentioned as factors that affect familiar relationship building [58]. There are also discussions on the familiarity from the veiw points of "robot movement" [59], "contact with robot" [60, 46], "learning of user behavior" [61], "facial expression" [62].

On the other hand, we focused on the relation between physiological phenomena of robot and closeness/affection, and expected that unconscious emotion sharing in co-experiences would change the relationship between humans and robots. Also, we considered that familiar and affection would be enhanced by feeling physiological phenomena in touching the robot.

Body movements, facial expressions, and speech are intentionally performed as expressive way for conveying emotions to the others; however, physical phenomena are involuntary expression which occur prior to the intentional representation of emotion. Accordingly, it is possible to create human empathy toward the robot unconsciously and to possibly give a gradual change to the user's own feeling/impression of the other.

4.1.3 Indirect Communication by Physiological Phenomena with Robot

We define the indirect communication as follows.

- A user is paying attention to a third party, other event, or other object, except the robot.
- The robot convey it's emotion to the user by involuntary expressions..

If indirect communication is able to increase sympathy and to enhance user's emotion, it is considered that effective mental care and robot therapy would be realized by using tactile interaction [63, 64] like a conversation with robot, touching, stroking and gripping.

First, we focus on the joint attention to an emotional photograph and verified how indirect communication between user and robot affects (1) user's emotion toward their subjective experiences and (2) the relationship between user and robot.

4.2 Related Works

4.2.1 Enhanceing User's Emotion by Physiological Emotional Expression of Robot

Related to the enhancement of users' emotions, there is research using robots' bodily movements. Matsumoto et al. [42, 43] showed that robots' bodily movements that fit the emotional context of videos caused users' emotions to change when users watched videos with the robots; robots' bodily movements made users more excited or relaxed as well as less depressed and afraid. In our study, we focused on physiological expression as involuntary expression, verifying whether physiological expression has the same effect as bodily movements.

Some studies have shown that direct manipulation and false feedback of a user's heartbeat with visual and auditory expressions changed the user's emotional or physiological state [44, 45]. In contrast, if these visual/auditory expressions of the heartbeat are represented with external audio and visual contents, the heartbeat expressions could lead to disturbance of the concentration on the contents or misunderstanding of the contents. To solve the problem, there are studies of heartbeat expression in tactile stimuli from vibrations to the user's chest [65]. In this research, we expected that users' emotions could be enhanced by tactile stimulation from the robot as the third person, while considering the influence on content. Tactile stimulation of the robot's physiological phenomena was expected to produce ambient stimulation to the user in a common context.

Yohanan et al. [26, 25] showed that the robot's emotional expressions, including movements of the lungs, purring emitted by a sound box and stiffness of ears, changed the participant's emotion in their human-robot experiments. In their study, the user's attention was focused on direct interactions with the robot, and the user evaluated his or her own emotions. On the other hand, in our study, the main focus was on indirect communication between the user and the robot with common contents. The participants were instructed to evaluate their impression not of the contents but of the robot. That is, we evaluated the user's emotions when the user concentrated on the content, not on the interaction with the robot.

4.2.2 Building Close Relationships with Robots

Kwak et al. [66] described that the physicality of the robot is an important factor for empathy, and Riek et al. [67] described that robots with appearance close to human beings are more likely to give empathy. From these results, it is considered that appearance of robot is a factor of sympathy. It is also shown that body movement, expression, utterance behavior and verbal contents are important for sympathy. Meanwhile, even with a virtual agent that does not have a body in the real space, it is possible to enhance the feeling of empathy by showing synchronous behavior duringperforming tasks such as games [68].

Yamano et al. [69] showed that not only the interaction duration increases but also the positive impression such as the familiarity to the robot increases as a result of synchronous changes of robot's facial expression to the user's one.

These are methods approaching the user by visual / auditory information. On the other hand, we aim to create empathy between users and robots by tactile expression of physiological phenomena.

The robot had advanced conversation ability and physical exercise ability, a stuffed robot with an animal appearance was adopted not to give a

Table 4.1: Mean and SD of arousal and valence in each category.

	Low Valence High Arousal		High Valence Low Arousal		High Valence High Arousal		Low Valence Low Arousal	
	Valence	Arousal	Valence	Arousal	Valence	Arousal	Valence	Arousal
Mean	2.617	6.236	7.276	3.550	7.439	6.240	3.249	3.872
SD	0.405	0.245	0.418	0.360	0.355	0.434	0.506	0.159

mechanical impression.

4.3 Verification System

The robot is a dog-like stuffed toy about 55 cm in height and weighing about 2.0 kg, containing our proposed physiological phenomena mechanism [70]. We redesigned the appearance to conform with that of a dog, which is a common pet. The robot's weight is about the same as that of a small dog. The experiment participants were seated where they could see the screen, and they held robots as if they were pets.

The mechanism is composed of breathing, heartbeat and body temperature, which can be controlled individually. The breathing mechanism also controls the abdominal motion and air flow of breath. The heartbeat is expressed by vibratory stimulation of the chest. The body temperature is expressed through heaters under the fabric.

4.4 Experiment 1: Enhancing Users' Emotion by Physiological Expressions

4.4.1 Experimental Design

Purpose of Experiment: Based on the results of the factor analyses and ANOVA for factor scores, we focused on the arousal axis of the robot's emotion and verified whether the user's own emotion in the experience of the contents was changed by arousal expression through the robot's physiological phenomena while they looked at photographs together.

Participants: Forty-seven university students aged between 19 and 24 years (27 males and 20 females).

Hypothesis: We set up the hypothesis as follows: The robot's physiological phenomena with high arousal enhance the user's own emotions while looking at the photos. The robot's physiological phenomena with low arousal

restrains the user's own emotions while looking at the photos.
Conditions: There were 12 conditions with two factors: A) physiological expression (A1 opposite of the photos, A2 matching the photos, A3 without physiological expression [only the impression of the photograph]) and B) emotions of the photograph (B1 high arousal – pleasure, B2 low arousal – pleasure, B3 high arousal – displeasure, B4 low arousal – displeasure). The experiment was conducted with 3 trials per condition. The order of all of the 36 trials was counterbalanced.

The physiological expression of the robot changed based on the parameters of arousal. In the "matching the photos" condition, when the arousal of the photo was high, the robot expressed the emotion of high arousal; breathing speed, heart rate and body temperature increased. When the arousal of the photo was low, the robot expressed the emotion of low arousal; breathing speed, heart rate and body temperature decreased.

The "opposite of the photos" condition (A1) means that the robot presented physiological phenomena of low arousal when the degree of arousal of the photo was high, and the robot presented physiological phenomena of high arousal when the degree of arousal of the photo was low.
Control of Photos as Experimental Stimuli: The affective ratings for the pictures in the International Affective Picture System (IAPS) were used for the emotional visual stimuli. These pictures were rated based on arousal, valence and dominance. The top 25% of pictures were extracted from 1,182 images based on ratings of arousal and valence. The pictures were divided into 4 categories: high arousal – pleasure, low arousal – pleasure, high arousal – displeasure and low arousal – displeasure. Inappropriate images were excluded by experiment collaborators, and 9 images were selected for each category. There were not enough photos in the low arousal – pleasure category, so the top 30% of pictures were re-extracted and selected based on ratings of arousal and valence. Table 4.1 shows the mean and SD of arousal and valence in each category. The 9 images for each category were counterbalanced among all participants.
Procedures and Instructions: Figure 4.1 shows the experimental environment. The participants were instructed that this experiment involved evaluating the impressions of photos, and they were lectured on how to hold the robot. After receiving the robot, the message "Please pay attention to the screen" was provided. A picture was presented for 10 seconds after the screen was blank for 5 seconds. The physiological phenomena of the robot changed 0.5 seconds after the presentation of the photo. After the screen changed to blank, participants released the robot and responded to the questionnaire.

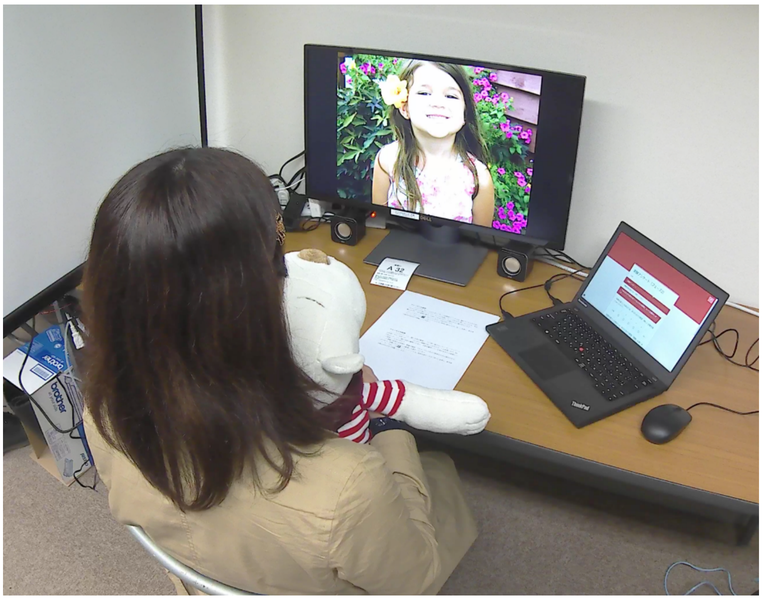


Figure 4.1: The experimental environment.

Evaluation Items: Each photograph was scored using a 5-level Likert scale with two parameters based on Russell's circumplex model. The parameters were scored using the following two questions: Q1 How pleasant was the photo? (1 = very unpleasant and 5 = very pleasant) and Q2 How stimulated were you by the photo? (1 = very calm and 5 = very aroused).

4.4.2 Result

Table 4.2 and table 4.3 show the means/SD and result of ANOVA (significance level: * $p < .05$). Regarding Q1, there was neither significance nor interaction between both factors. Regarding Q2, there were interactions between factor A (physiological expression) and factor B (emotions of photographs). Based on the result of multiple comparisons of factor A, participants felt more excited with A2 than A1 in the condition of B1, and participants felt more excited with A1 and A2 than with A3 in the condition of B2. From the result of multiple comparisons of factor B, participants felt more excited with B2 than with B1 in the condition of A1.

Table 4.2: Mean and SD in experiment 2.

		A1				A2				A3			
		B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4
Valence (Q1)	mean	3.038	3.083	3.053	3.068	2.894	3.106	3.152	2.970	3.114	2.924	3.053	3.098
	SD	1.190	1.162	1.251	1.169	1.287	1.130	1.228	1.218	1.152	1.172	1.214	1.173
Arousal (Q2)	mean	2.947	3.364	3.212	3.258	3.364	3.386	3.045	3.174	3.212	3.023	3.197	3.167
	SD	1.170	1.032	1.108	1.172	1.094	1.071	1.167	1.158	1.060	1.228	1.090	1.207

Table 4.3: Result of ANOVA in experiment 2.

	A		B		AB		Interactions
	F	*p*	*F*	*p*	*F*	*p*	
Valence (Q1)	0.07	0.932	0.299	0.826	0.816	0.557	–
Arousal (Q2)	0.671	0.512	1.111	0.344	2.482	0.022*	A1(B2-B1), B1(A2-A1), B2(A3-[A2, A1])

4.4.3 Discussion

First, we discuss how the physiological expressions of the robots affected the impressions of pleasure and arousal received from the photographs. The physiological phenomena of the robot changed only according to the arousal (Q2). It was confirmed that changes in physiological expression based on arousal influences arousal in the user's own emotional experience and does not affect pleasure.

Second, we discuss what kind of emotion caused by the photograph is affected by physiological expressions. In evaluation item Q2, there was a significant difference in the impression of the photograph only in the conditions in which valence (pleasure – displeasure) was high (= pleasure). We selected displeasing pictures that were not inappropriate for the experiment, so there was a possibility that the influence on emotions was restricted.

Last, we discuss how users' own emotional experiences were changed by the physiological expressions of the robots while looking at visual content based on the results, as follows: (1) When the content was pleasure – high arousal, the empathic physiological expression enhanced the user's arousal based on the content. (2) When the content was pleasure – high arousal, physiological phenomena that were not sympathetic decreased the user's arousal based on the content. (3) When the content was low arousal – pleasure, the user's arousal based on the content increased according to the physiological expression of the robot, regardless of the kind of emotion shown in the content.

It was shown that it is possible to enhance or repress the emotion of the user through the physiological expression of the robot when the arousal of the content is high. Furthermore, when the arousal of the content is low, the physiological phenomena enhance the emotion of the user, regardless of whether the physiological expression of the robot is empathic or not.

Based on these discussions, we need to consider the following problems: This study could not clarify the physiological parameters related to the emotional expression of valence, and stronger stimuli for displeasure should be prepared using video to extend the stimulation time.

4.5 Experiment 2: The Impression of Relationship Between User and Robot by Indirect Communication

Contents of Experiment

Purpose The purpose of this evaluation is to clarify a) which factor on the impression of the robot is affected by emotional expression by the physiological phenomenon of robot and b) how the impression of robot is changed by physiological phenomenon. First, we conducted factor analysis based on the evaluation for impression of the robot using SD method. Here, we first clarify the factor related to closeness with the robot. Second, for each factor, we compare the robot with physiological phenomena to the robot without these phenomena.

Conditions There were 2 conditions of a factor: the robot with physiological phenomena (*WP*) and the robot without physiological phenomena (*NP*).

Experimental Stimulus In *WP* condition, the physiological phenomena of the robot are changed corresponding to time-series change of arousal level of the video contents. The two video contents with fear and moving emotion for each were prepared referring to the Russell's circumplex model [51]. Both videos are cartoon, with clipped five minutes of scene. Arousal levels in various scenes are labeled in 101 levels from 0 to 100 by two collaborators, and the robot's expression was controled by the level. Figure 4.2 shows the time-series change of parameters in the videos . The order of videos and conditions were counterbalanced within participants. Ribbons of different colors to indicate each different robot are attached to the robots' necks for each trial.

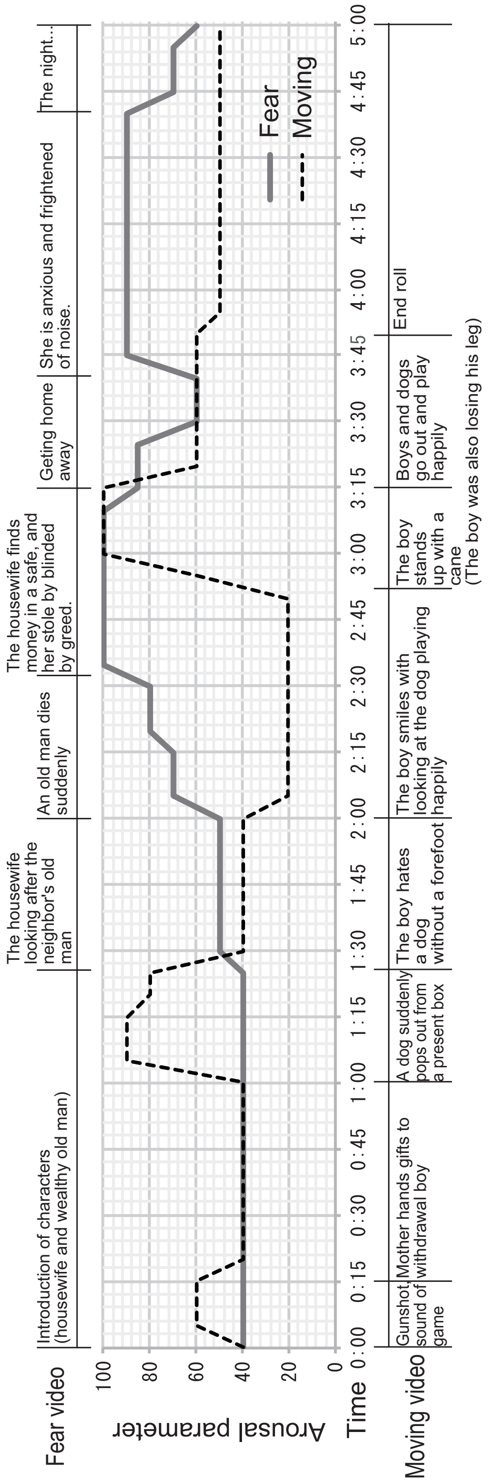


Figure 4.2: Time-series change of arousal parameter in the video scenes

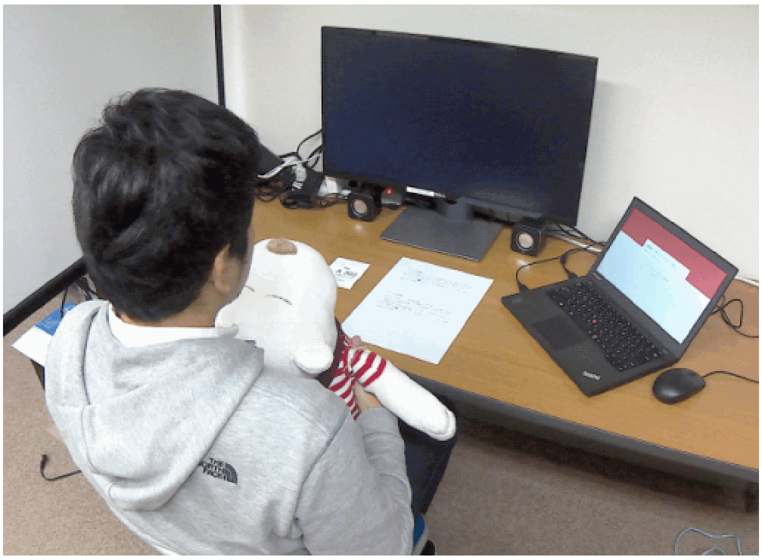


Figure 4.3: Experimental environment

Participants Twenty-five university students aged between 19 and 24 years (14 males and 11 females).

Procedures Figure 4.3 shows the experimental environment. The participants were instructed about this experiment, and they were lectured on how to hold the robot. After receiving the robot, 5 minutes video are presented. After the screen changed to blank, participants released the robot and responded to the questionnaire.

Evaluation items The participant answered the impression of the robot for twenty-nine adjective pairs (see Table 4.4) using SD method.

Factor Analysis

Extraction of Factors Factor analysis was performed on the results of the SD method ratings for the 29 adjective pairs. Figure shows the eigenvalues and scree plots. According to the difference in the eigenvalues by a major-factor method, we adopted two factors. The cumulative contribution ratio was 57.9 %. The factor matrix was rotated using the Varimax method. Figure 4.4 shows the factor loadings.

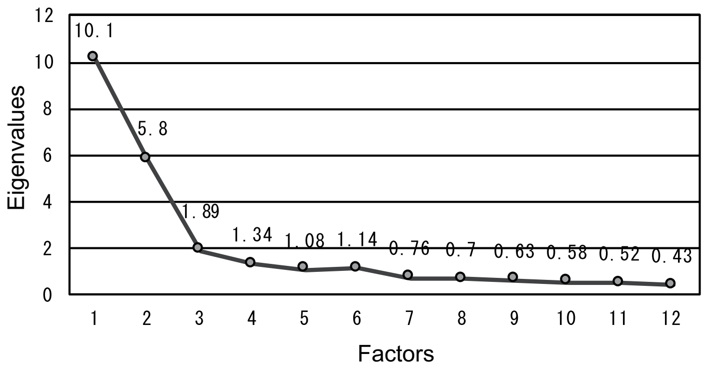
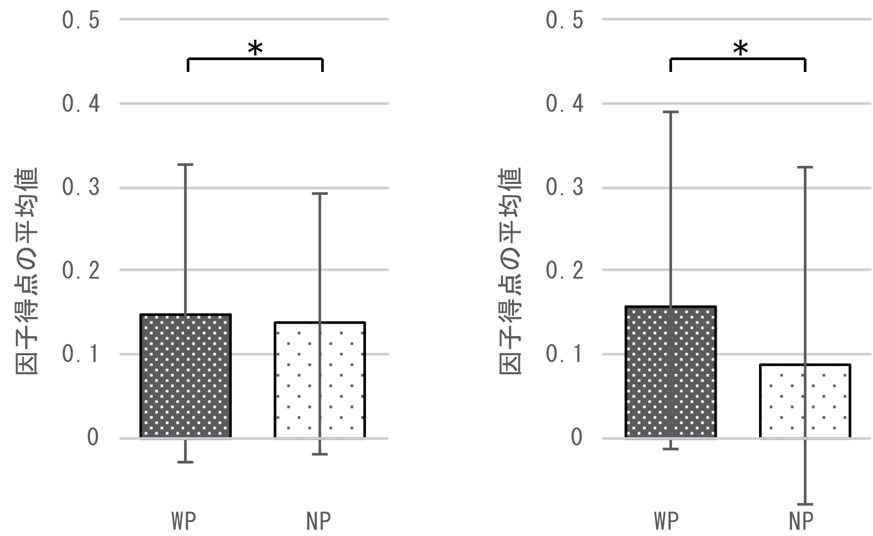


Figure 4.4: Eigenvalues and scree plots

Regarding first factor, adjective-pairs such as "formal – casual", "unapproachable – approachable", "unfamiliar – familiar" and "boring – interesting" and showed the value of 0.6 or more, so it is considered that these adjective pair directly shows the relationship between participants and robots. Also, adjective-pairs such as "cold – warm", "dark – bright", "empty – fulfilling" and "hateful – lovely" showed the value of 0.6 or more, so it is considered that these adjective pairs show metaphorical expression of relationships with robots. Accordingly, the first factor was named "closeness ."

Regarding second factor, adjective-pairs such as "mild – intense", "slow – quick", "insensitive – sensitive" and "passive – active" showed the values of 0.6 or more, so it is considered that these adjective pairs directly show sensitivity of robot's emotion. Accordingly, the first factor was named "sensitivity."

Comparison of condition of physiological phenomena Standardized factor scores were calculated using standardized partial regression coefficients. Figure 4.5 shows the result of ANOVA (analysis of variance) for each standardized factor score in order to compare among the conditions (significance level: * $p < .05$). The result showed significant differences in both factor of "closeness" and "sensitivity" between conditions of WP and NP.



(a) The "closeness" factor (b) The "sensitivity" factor

Figure 4.5: Result of ANOVA based on standardized factor scores of each condition of physiological phenomenon

Discussion of The Impression of Relationship Between User and Robot by Indirect Communication

We discuss how the user's impressions of "closeness" and "sensitivity" for the robot are changed by physiological phenomena of the robot.

Regarding the factor of closeness between user and robot, there is a possibility that the user's sense of familiarity to the robot was improved by perceiving the physiological phenomena of the robot while watching the video together. This result suggests that emotional sharing by physiological phenomena can become an important factor in building relationship between user and robot.

The factor of sensitivity of robot showed a possibility that the user perceived the robot's sensitive behavior/emotion by perceiving the physiological phenomena of the robot while watching the video together. It is conjectured that the physiological phenomena is deeply related to the assumed inner state of the robot, that can express a characteristic of the robot even if the appeared change was only the physiological state.

From these discussions, we assume that the familiar relationship and sensitive emotional change of the robot are perceived by the physiological expression of the robot in the user's arm with common contents.

For further discussions, we should consider other contexts such as the scene in the bed, resting, or dinner, to focus on daily situation without strong emotions. Also, not only the arousal parameter in the Russell's circumplex model but also the pleasure parameter should be verified by other experiments to consider familiarity and active impressions are increased or decreased by the suitable or unsuitable emotions.

4.6 Summary

In this chapter, we discuss indirect communication between human and a robot through physiological phenomena, which consist of breathing, heartbeats and the body temperature, and which express robot's emotion. We set a situation with joint attention between the robot and user to an emotional contents, and evaluated whether both the user's emotional response to the content and the user's impression on relationship between the user and the robot were changed by the physiological expressions of the robot. The results suggest that the physiological expression of the robot would make the user's own emotion in the experience more excited or suppressed, and that the robot's expression would increase impressions of closeness and sensitivity.

First, we focused on the scene in which the user holds on the robot during watching a movie to compare the impressions for the robot with or without physiological phenomena. The main result showed that the physiological phenomena elevated both factors of "familiarity" and "sensitivity"

Second, we verified whether the user's own emotion in the experience of the contents changed through the arousal expression of the robot's physiological phenomena while they looked at photographs together. The results suggest that it is possible that physiological expression makes users more excited and more relaxed when the content looked at with the robot involves pleasure and high arousal, and the expression makes users excited when the content looked at with the robot involves low arousal.

In future work, the system is expected to contribute to medical and nursing care by elevating and relaxing a user's emotions and to build the close relationship with the robot through the emotional expression by physiological expression of a partner robot in the user's daily life.

Table 4.4: Adjective pairs, factor loadings and factor score coefficients

Adjective pairs	Factor loading		Factor score coefficients	
	First factor	Second factor	First factor	Second factor
severe–affectionate	**0.754**	0.032	0.081	-0.021
pleasant – unpleasant	**0.881**	-0.059	0.098	-0.039
unfamiliar – familiar	**0.778**	0.083	0.082	-0.014
dangerous–safe	0.619	-0.442	0.083	-0.089
cold–warm	**0.690**	0.436	0.061	0.044
annoying–adorable	**0.830**	-0.016	0.091	-0.031
formal – casual	**0.805**	0.198	0.081	0.003
unintelligible–intelligible	**0.481**	0.387	0.039	0.043
unapproachable–approachable	**0.744**	0.004	0.081	-0.025
dark–bright	**0.793**	0.313	0.076	0.021
egoistic–considerate	0.634	0.023	0.069	-0.018
mechanic–human-like	0.381	0.331	0.030	0.038
empty–fulfilling	**0.557**	0.521	0.043	0.061
unamusing–amusing	**0.489**	0.676	0.030	0.087
unpleasant–pleasant	**0.795**	0.104	0.083	-0.011
unlike–like	**0.804**	-0.067	0.090	-0.038
bored–interesting	**0.514**	0.658	0.034	0.084
bad–good	**0.841**	0.115	0.088	-0.011
simple–complex	0.000	**0.685**	-0.023	0.105
late–early	-0.055	**0.773**	-0.032	0.121
slow–fast	-0.071	**0.896**	-0.038	0.140
calm–intense	-0.444	**0.673**	-0.072	0.119
passive–active	0.156	**0.769**	-0.009	0.113
hesitant–bullish	0.028	0.516	-0.015	0.078
restrained–gaudy	0.265	0.556	0.010	0.076
broody–cheerful	**0.749**	0.318	0.071	0.023
insensitive–sensitive	0.033	**0.785**	-0.023	0.120
foolish–clever	0.218	0.588	0.004	0.083
weak–strong	0.050	0.670	-0.017	0.101

Chapter 5

Discussion

5.1 Summary of this Dissertation

For next-generation robots, it is assumed that robots do not unilaterally assist users but rather become close partners by enriching emotions while building relationships between humans and robots through communication. The purpose of this research is for the user to recognize and interact with the robot as a living thing rather than an artificial machine by the robot directly expressing physiological phenomena as basic life activity.

In order to realize long-term communication between a robot with physiological phenomena and human beings, we raised the following three discussion points.

Expression of "Sense of Living"

Anthropomorphic robots are being required to play a role as substitutes for humans or pets. If household robots become popular, long-term relationships in daily life will occur. Among them, scenes in which children live with pet robots instead of pets can also be considered. It is also necessary to discuss the influence of robots on children and the ways in which to communicate between humans and robots for long hours. For example, the necessity of learning about life is being discussed in terms of animal cruelty against pets.

It is considered that, if the user communicates with the robot as if it were a pet or a human being, the user must feel that the robot is "alive." Also, the robot must have a mechanism to indicate that it is alive, just as a human being or a pet is. Furthermore, it is necessary to communicate with humans via these mechanisms.

Emotional Expression Based on Mechanisms of Life

Humans individually have an inner state as an instinctive mechanism of animals for crisis avoidance and survival, and they generate inner states, such as feelings and desires, based on this [71, 72].

However, artifacts do not have such inner states and consciousness that enable cooperation with others. Also, some studies raising these problems are ignored by design based on biological instinctive mechanisms. It is an important problem that must be discussed to design a robot that is an artificial machine that can communicate with human beings.

Regarding the representation of robots, various studies on topics such as voluntary expressions—including body movements and facial expressions, utterance contents and utterance methods—are being conducted. On the other hand, active discussions focusing on physiological phenomena as involuntary expressions have not been conducted.

Emotional reactions are caused by a potential external condition acting on autonomic nerves. This mechanism is the same in animals. There are more than a few emotional reactions, potentially affecting emotions and their expression. Because of this, physiological phenomena should be discussed as a basic emotional expression.

Robots' Coexistence with Humans as Living Beings

Humans are social animals and live by constantly making relationships with others and relying on each other. In social groups, communication using various expressive modalities is done in order to build and cooperate with others.

It is said that a lack of communication causes various problems, including dementia and the deterioration of mental health. Robots are expected to be utilized in these situations by being anthropomorphic. However, it is hard to say that these robots have sufficient elements for anthropomorphism, as they have no emotional expression based on the living inner state. There needs to be a discussion of a method for users to recognize robots as live existences, such as those of real pets, and a determination of whether users and robots can communicate with each other and build close relationships.

5.2 Summary of Evaluations

Expression of "Sense of Living"

Based on the evaluation of representations of life through the breathing of robots and expressions on the states of life and death, the speed of the robot's breath showed the possibility of expressing a detailed state of life for the robot. It was also shown that the "dead" state of the robot is perceived when there is no breathing in contrast to the "living" state of the robot. In addition, the speed of the robot's breath showed the possibility of expressing the detailed internal state of living of the robot.

5.2.1 Body-emotion Model Based on Biomechanics

We discussed the related studies about the categorization of emotion and feeling and the mechanism of physiological phenomena of humans and described the concept of the body-emotion model. We verified the emotional factors of the robot's physiological phenomena—such as the breathing, heartbeat and body temperature—through a factor analysis and an analysis based on standardized factor scores. From the result, we assumed that the arousal is expressed by all three physiological phenomena: the breathing, heartbeat and body temperature. High respiration rates, high heart rates and high body temperatures express high arousal in response to the robot.

Because of our verification results, it is suggested that the activity in the autonomic nervous system the and emotional arousal are related to each other, and it is considered that a design of the BEM—which involves the perception of the external situation, the matching with the memory, the change of the autonomic nervous parameter and the representation of the physiological phenomena—is effective. From these discussions, we designed the inner design of a robot by BEM based on a simplified model of human mechanisms.

Indirect Communication Through Physiological Phenomena

We proposed indirect communication between humans and robots as emotional communication through involuntary physiological phenomena in the daily lives of users and robots, and we evaluated the influence of robots' emotional expression that is expressed using the body-emotion model on users' emotions. We defined indirect communication as a situation in which intentional communication is not conducted and emotional interaction is caused by involuntary physiological phenomena.

We verified how indirect communication between users and robots affects (1) the relationships between the users and robots and (2) the ways in which users' emotions toward their subjective experiences are changed. The results suggest that the physiological expression of the robot would make the user in the experience more excited or suppressed and that the robot's expression would increase impressions of closeness and sensitivity.

5.3 Future Perspective of Human-Robot Communication Through Physiological Phenomena

We discussed the possibility of living together and recognizing changes in the way of living together with the robots.

5.3.1 Possibility of Robots Being Treated as Living Beings

We clarified that the physiological phenomena presented by the robot represent the living state and dead state of the robot. Such recognition by the user has a great influence on how the user associates with the robot.

First, by showing various aspects of the robot's living state, it is possible for the user to recognize that the physical condition and the internal state related thereto are not always constant. If it allows users to recognize or anticipate the death of the robot, it also allows the user to think about the finiteness of the robot's life. In the future [73], if it is possible to express the life and death of the robot, it can be expected to be useful for learning about life in educational institutions and environments where it is difficult to keep pets [74, 75].

Second, the combination of "voluntary expressions"—such as body motion, which has been studied—and "involuntary" emotional expressions from robots through physiological phenomena can also be expected for complex emotional expression; for example, it is possible to express an admirable appearance that seems healthy to the user, even though the robot is about to die.

Third, it is expected that the robot will be treated as an animal, not as a machine, by accumulating the experience of the user living with the living robot. Specifically, robots that are machines do not need to be taken care of as pets are, except for maintenance. However, communication varies depending on the degree of care of the animal, and pets is life-threatening if you disregard feeding. On the other hand, it is thought that attachment is born through a user feeling the healthy state of the robot and experiencing worry about disease while the user takes care of the robot in the long term. In this way, the expression of the robot's life sense has the possibility of changing the robot unconsciously to an irreplaceable existence and promoting long-term communication.

5.3.2 Complex Emotional Communication with Robot

As discussed earlier, humans are social animals and live by constantly making relationships with others and relying on each other. In social groups, communication using various expressive modalities is done in order to build and cooperate with others. Also, in the communication with others, the expression of inner states is adjusted based on the interests of the participants and both parties.

Conventional robots convey intentions to users with intentional, direct and voluntary expressions. On the other hand, the involuntary expression of the internal state through the physiological phenomena is the expression of the unconscious emotions. Emotions expressed voluntarily and emotions expressed involuntarily may not match in some cases. A lie is a typical example of this. Even animals may endure eating bait in accordance with the orders of their owners, but they may roughen their breathing, drool or tremble. If a robot can express a combination of realistic voluntary expressions, such as facial expressions and body movements, in combination with real involuntary expressions, by using real intentions and lying, it can be said that the robot has a more complicated internal state than a pet. On the other hand, there is a possibility of creating doubts about robots. However, it is suggests that the robot have also a real human existence.

5.3.3 Physiological Emotional Exchanges in Mental Health Care

Communication support using a robot is being required to play a role as a substitute for humans with the decreasing and aging population. Arousing the emotions of patients has been one of the important factors in medical and nursing care recently. Many types of pet robots have been developed as communication partners for patients, but these robots have none of the mechanisms of living animals. Because positive influences on patients due to physiological phenomena have been reported, the physiological phenomena in animal therapy are considered to be important.

Existing robots can express emotions only through voluntary movements, such as voice and body movements. There are possibilities that the robot will always emit sound or that a moving robot may annoy the user in some cases, and there is a possibility of getting tired from communication. Emotional expressions due to physiological phenomena may unknowingly influence feelings, even in a situation in which the user is not conscious of the robot. Furthermore, since the user is unintentionally informed of the emotion of the robot via contact, the elderly can present emotions without interruption while watching television or listening to music on the bed.

When compared with animals in animal therapy, the robots can present and induce emotions according to the emotions of the users. It is possible to raise the emotion of the depressed user or calm the user from an excited state by recognizing the emotion of the user. In addition, it was shown that the closeness between user and robot was advanced by the robot expressing emotions sympathetic to the user's emotions. From this, we expect to be able to support long-term care by sharing feelings and building close relationships, regardless of the situation.

By using a robot that expresses a living state through physiological phenomena, an effect of the mental care exceeding that of animal therapy can be expected, and we expect to provide care and welfare support in place of human beings.

5.4 Summary

It is expected that robots will not unilaterally assist users but rather will become close partners by enriching emotions while building relationships between humans and robots through communication. We discussed the following topics to realize these aspects of communication: the expression of the "sense of living," emotional expression based on the mechanism of life and the robots' coexistence with humans as living beings.

Regarding the representation of the robots' sense of life, it is thought that the recognition that the robot is alive improves not only the moral effect on the finiteness of life but also attachment to the robot in long-term communication. Regarding the emotional-expression mechanism that is based on life, it is expected that the robot will be able to display a complicated internal state close to that of humans by combining the intentional expression of emotions and involuntary emotional expressions. If a robot can express realistic voluntary expressions, such as facial expressions and body movements, in combination with real involuntary expressions by using real intentions and lying, it can be said that the robot has a more complicated internal state than that of a pet. By using a robot expressing a living state through physiological phenomena, an effect of mental care exceeding that of animal therapy can be expected, and we expect to provide care and welfare support in place of human beings.

Chapter 6

Conclusion

6.1 Summary of this Dissertation

It is expected that robots will not unilaterally assist users but rather become close partners by enriching emotions while building relationships between humans and robots through communication. In this dissertation, we discussed the following topics to realize these aspects of communication: the expression of the "sense of living," emotional expression based on the mechanism of life and robots' coexistence with humans as living beings. The major topics addressed were as follows:

1. Expression of the "sense of living," "emotion" and the design of the body-emotion model (Chapter 3).
    - The evaluation of living expression through physiological phenomena.
    - The analysis of emotional factors through robots' physiological expressions.
    - The design of the body-emotion model and the mechanism of physiological expressions for robots.
2. The effects of the robot's physiological emotional expression on indirect communication (Chapter 4)
    - The effect of the user's impressions of the relationship between the user and the robot through the physiological contact with the robot.

- The effect of the user's own emotion in the experience of the contents through the physiological contact with the robot.

In chapter 3, we focused on the robots' expression of physiological phenomena, proposed the body-emotion model (BEM), which concerns the relationship between the inner state of robots and their involuntary physical reactions. We proposed a stuffed-toy robot system: BREAR—which has a mechanical structure to express the breathing, heartbeat, temperature and bodily movement. The result of experiment showed that a heartbeat, breathing and body temperature can express the robot's living state and that the breathing speed is highly related to the robot's emotion of arousal. We reviewed the experimental results and emotional generation mechanisms and discussed the design of the robot based on BEM. Based on our verification results, we determined that the design of the BEM-which involves the perception of the external situation, the matching with the memory, the change of the autonomic nervous parameter and the representation of the physiological phenomena—that is based on the relationship between the autonomic nervous system and emotional arousal is effective.

In chapter 4, we discussed indirect communication between humans and robots through physiological phenomena—which consist of the breathing, heartbeats and body temperature—that express robots' emotions. We set a situation with joint attention from the robot and user on emotional content and evaluated whether both the user's emotional response to the content and the user's impression of relationship between the user and the robot were changed by the physiological expressions of the robot. The results suggest that the physiological expression of the robot makes the user's own emotions in the experience more excited or suppressed and that the robot's expression increases impressions of closeness and sensitivity.

6.2 Further Research

"Pleasure" Parameter of Physiological Phenomena

From the results of the factor analyses for each expression of the robot's physiological phenomena, we determined that both the factors of heartbeat and body temperature correspond to the arousal emotion of the robot from these results, whereas the robot's breathing involves two factors: arousal and pleasure.

Arousal, in particular, is affected by the speed of the robot's breathing. On the other hand, the breathing of robot may result in a pleasant factor. For example, there are factors, such as the time difference between inspiration and exhalation, that act as autonomic nervous influences. Similarly, regarding the heartbeat, it is necessary to verify whether heartbeat fluctuation or arrhythmia affects parameters other than arousal level.

Detection of User's Emotions Through the State of Physiological Phenomena

We constructed the emotional expression model based on the physiological phenomena of the robot. There is the possibility that the physiological emotional expression of the robot unconsciously enhances and restrains the user's emotions.

If the robot picks up the emotion of the user and presents emotion according to the user's emotion, stronger empathy and control of feeling are possible. It is necessary that the design of the non-invasive user's emotion recognition mechanism that is based on physiological phenomena and the robot's emotional expression framework be based on the body-emotion model.

Improve Attachment by Expressing the Finiteness of Life

It is possible to verify the improvement of attachment due to the finiteness of life by using a robot to express long-term life and death through physiological phenomena.

Robots Improve Mental States and Motivation

It is possible to verify the effect of improving the user's depressed state and increasing the user's motivation by presenting the physiological phenomena according to the state of the user while the robot gets closer to the user.

6.3 Future Directions

It is expected that robots will not unilaterally assist users but rather become close partners by enriching emotions while building relationships between humans and robots through communication. We discussed the following topics to realize these aspects of communication: the expression of the "sense of living," emotional expression based on the mechanism of life and robots' coexistence with humans as living beings.

Regarding the representation of the robots' sense of life, it is thought that the user's recognition that the robot is alive improves not only the moral effect on the understanding of the finiteness of life but also the attachment to the robot in long-term communication. Regarding the emotional expression mechanism based on life, it is expected that the robot can display a complicated internal state close to that of humans by combining intentionally expressed emotions and involuntary emotional expressions. If a robot can express a combination of realistic voluntary expressions, such as facial expressions and body movements, in combination with real involuntary expressions by using the real intentions and lying, it can be said that the robot has a more complicated internal state than that of a pet. By using a robot expressing a living state through physiological phenomena, it can be expected that the effect of mental care will exceed that of animal therapy, and we expect to provide care and welfare support in place of human beings.

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List of Publications

Journal Articles

1. Naoto Yoshida, Tomoko Yonezawa, ぬいぐるみロボットの呼吸が生きている状態と内部状態に与える効果の検討 (Investigating Effects of Breathing Expression of a Stuffed-Toy Robot on Living and Inner State), in Japanese, IEICE Journal in Japanese, Vol.J101-D, No.02, Feb. 2018, in press.
2. Naoto Yoshida, Tomoko Yonezawa, ユーザ視点位置に応じた描画エージェントを用いた実空間内注視コミュニケーションの検証 (Investigation of Spatial Gaze-communication Using Virtual Agent Based on Motion Parallax in Real Space), in Japanese, IEICE Journal in Japanese, Vol.J99-D, No.9, pp.915-925, 2016.
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1. Naoto Yoshida, Tomoko Yonezawa, 人間–ロボットの生理現象を介した共体験における積極性と親密性 (Improvement of intimacy by co-experiences through robot's physiological phenomena), in Japanese, Information Processing Society of Japan Kansai Branch, B-102, 2017.
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