Journal of Theoretical and Applied Information Technology
30th September 2017. Vol.95. No.18

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

EMOTIONAL MOTION PROTOTYPING FOR A SOCIAL ROBOT UTILIZING A DELTA ROBOT

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ABSTRACT

Today, a variety of social robots capable of interacting and communicating with humans has begun to emerge. Existing social robots mainly utilize a voice and/or a small screen for emotionally interacting with humans despite many possibilities of physically expressing emotional motion. Thus, this research aims to build methods for emotional motion prototyping and create a prototype of a social robot based on the kinematics of the Delta robot. For this research, literature related to emotional motions of social robots and humans is explored, and emotional motions of humans is categorized based on six basic human emotions in order to analyze existing social robots. Moreover, through analyzing the cases, we propose methods for emotional motion prototyping. Based on these, a prototype of a social robot is developed based on the kinematics of a Delta robot and is tested. In this paper, we present ways to create emotional motions of social robots and experimental experience of a prototype of a Delta-robot-based social robot. Further work in this research is to develop an actual social robot based on the prototype.

Keywords: *Social Robot, Delta Robot, Emotional Motion, Emotional Interaction, Motion Prototyping*

1. INTRODUCTION

Robotic technology has mainly been studied for the benefit of humans in various fields, and many studies have concentrated on industrial robots [1]. Today, the miniaturization of electronic parts, the decrease in prices, and the generalization of smart devices has enabled robotic technology to be studied for the home and social contexts [2]. Because of these reasons, social robots capable of interacting and communicating with people has begun to emerge based on Internet of Things (IoT) technology. Emotional interaction between robots and humans is an important part in the development of social robots, and to allow for emotional interaction, researchers tried to create dynamic, emotional motion that utilizes electronic parts such as motors and sensors, or uses a smartphone [1]. However, these motions are limited.

The ultimate goal of this study is to develop a social robot that can support diverse emotional movements based on a Delta robot capable of providing quick and different movements in a restricted space. As the part of an on-going project [3], this paper presents how to create emotional motion using Delta robot kinematics and its speed according to six basic human emotions.

This study firstly explores literature related to emotional motions of social robots and humans in order to understand developmental tendencies of social robots and relations between social robots and emotional motions. Through these explorations, we categorize emotional motions of humans based on six basic emotions. Through investigating and analyzing state-of-the-art cases on emotional motions of social robots, we recognize the degree of coverage of human emotional motions in social robots. Moreover, emotional motions of existing social robots are extracted. Based on this, we propose methods to express emotional motions of social robots. Finally, for implementing the proposed methods, we create and test a working prototype that can effectively generate emotional motions utilizing a Delta robot

This research is limited to implement emotional motions for a social robot. In future research, we will conduct user experience evaluation of this prototype to prove the viability of the proposed emotional motion and will further develop this prototype that allow to interact and communicate with users based on sensor technology.

Among many methods of representing emotions, this research conducts a study focusing on

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

emotional motions of social robots, which represent their emotions with physical movements. This study contributes to the development of a social robot by proposing how to create diverse emotional movements of a social robot.

The rest of this paper is organized as follows. Section 2 presents literature about social robots and emotional motions in social robots. In section 3, we provide classification of human emotional motions according to six basic emotions. Section 4 presents case studies that are conducted through exploring and analyzing three recent cases. The methods for emotional motion prototyping are proposed in section 5. In section 6, we describe the development of a working prototype utilizing a Delta robot, providing emotional motions by combing basic three motions of a Delta robot. Finally, section 7 concludes this paper with a review of the research, findings, limitations of the research, and further research.

2. SOCIAL ROBOTS AND EMOTIONAL MOTIONS

2.1 Social Robots

A robot has been developed to replace difficult jobs of humans [2]. Because of this, a robot works in "highly structured environments" with "limited human interaction" [4]. Recently, development of interaction and sensor technologies has enabled robots to interact with humans within the scope of human's daily life. These robots are considered as social robots. Social robots are, by definition, social autonomous robots that are devised "to interact with humans or other physical agents" and these "exhibit social behaviors such as recognizing, following and assisting their owners and engaging in conversations" [2, 5]. Using this definition, social robots can be considered to have the ability to communicate verbally and non-verbally with humans through employing artificial intelligence and robotics. Since the 1990s, social robots have been developed in the field of robotics, and various studies related to emotions have been going on. Recently, the social robot industry is expanded because social robots are connected on the Internet, and social robots begin to be regarded as new touchpoints that bridge between physical spaces and digital services in diverse field.

2.2 Emotional Motions in Social Robots

Many researchers have studied emotional motions of humans since behaviors and gestures are necessary for conversation in human communication [6]. The emotional expression by humans mainly occurs in the upper body, and the shape, position, speed, and frequency of the hands and arms are significant elements can be considered for expressing their emotions [7]. In general, robots have been made similar to humans when expressing emotions, and this can be the reason for many studies on humanoid robots. However, according to Mori's theory of the uncanny valley [8], people are afraid rather than feeling at ease when human-like robots make unnatural motions. Recent social robots are not shaped like a humanoid robot with unnatural motions but take familiar forms capable of providing comfort to humans.

To express their emotions, social robots mainly include a small display such as a smartphone and an LCD screen because of limitations of expressing emotions with physical movements. Recent social robots, which are mainly located in the home, cannot move their neck, arms, hands, and bodies freely. These social robots just support motions specific to their appearance for expressing their emotions. Thus, well-designed physical movements are needed.

3. CLASSIFICATION OF HUMAN EMOTIONAL MOTIONS

For effective communication between humans and social robots, emotional motions of social robots need to be developed based on emotional motions of humans. Thus, in this section, we explored movements applicable to social robots through classifying emotional motions of humans based on literature.

With regard to evolutionary theory, emotional expressions of humans and animals were investigated by Darwin [9]. He argued that facial expressions and gestures expressing human emotions have the 'universal nature of expressions' because the emotional expressions are inherent and genetic. Also, Wallbot tried to categorize motions expressing certain emotions through recording and analyzing actress' and/or actors' emotional plays [10]. Moreover, Coulson classified human's body motions depending on certain emotions. He investigated emotional motions of humans through "computer-generated mannequin figures" with emotional postures [7].

As shown in Table 1, we categorized nonverbal emotional expressions of humans based on Darwin's, Wallbot's, and Coulson's studies depending on "Ekman's six basic emotions" of humans: "anger, disgust, fear, happiness, sadness,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

and surprise" [11]. From the categorization, we can recognize that each certain emotion has different nonverbal movements.

In order to apply these different emotional motions to social robots, the physical movements of social robots need to be controlled by the speed and direction freely. This enables us to express different emotions with dynamic and active movements, and with motionless. We will apply these categorized emotional motions to our prototype of social robots.

4. CASE STUDIES

4.1 Emotional Motions of Existing Social Robots

We explored state-of-the-art cases to recognize how the categorized emotional motions are applied to existing social robots. For this we selected recent several social robots that have different physical movements. Through these explorations, we were able to recognize how to express and limitations of emotional movements of social robots.

Keepon was developed by Kojima for helping the social development of disabled children. Keepon is a "small", soft, yellow "creature-like" robotic toy [12]. Keepon supports two types of motion: 'attention' and 'emotion'. The attention occurs when its' embedded camera recognizes a human face, and is operated by nodding. On the other hand, the emotion supports three motions capable of expressing pleasure, excitement, and fear. These motions are operated by rocking, bobbing, and panning respectively [13]. Keepon generates dynamic motions by controlling the angle and speed of motion.

Jibo, one of the most popular social robots, was developed by Breazeal. Jibo is composed of three cylindrical shapes with different angles. Since each shape is connected, motion of one shape affects other shapes. Through this, Jibo can generate different movements and poses although Jibo has only 360-degree rotational movement based on a DC motor [14]. Also, Jibo has been operated using digital and physical motions together when expressing its emotions, and it can make more natural interaction by controlling the speed of motion [15]. Moreover,

Table 1: Categorization of Human Emotional Motions and Postures

	Darwin (1872/1965)	Wallbot (1998)	Coulson (2004)
Anger	• Body trembles • Pacing up and down • Head erect • Chest expanded	• Lifting the shoulders • Arms stretched out frontal • High movement activity • Highest expansiveness	• Moving forwards • Backwards head bend • No chest bend • No abdominal twist • Arms raised forwards
Disgust	• Gestures as if to push away • Shoulders raised	• Shoulders backward or forward • Head downward • Arms crossed in front of chest • Less movement activity	• Moving backwards • Elbow stretched • Abdomen twist
Fear	• Head sinks between shoulders • Motionless or crouches down	• Shoulders moving forward • Opening and closing of the hand • Movement activity	• Moving head backwards • Chest bend • No abdominal twist • Elbow bend
Sadness	• Motionless • Passive • Chest contracted	• Body collapsed • Least movement activity	• Moving backwards • Head bend to downward and forward • Elbow bend
Surprise		• Arms stretched out frontal (interest) • Movement activity	• Moving head backwards • Abdomen twist • Shoulder swing • Abdominal twisting
Happiness	• Jumping • Clapping • Head nods to and fro • Body held erect • Head upright	• Less movement activity	• Shoulder swing • Arms stretched upward • Moving head backwards

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

users can create their own motions through the Jibo software developer kit (SDK). Although Jibo can generate different motions with a single rotary movement, it shows a lack of various emotional expressions.

Tega, recently developed to help children learn languages, uses "the squash and stretch" that is the most important principle of animation to produce motion [16]. Tega consists of a cylindrical shape and several actuators to generate dynamic movement [17]. It provides the natural movement by utilizing digital and physical motions at the same time.

4.2 Case Analysis

Through exploring the cases, we analyzed emotional motions used in existing social robots based on the categorization of human emotional motions and postures. Table 2 summarizes the results of case analysis.

Keepon does not follow emotional motions of humans. This social robotic toy supports simple motions for expressing its emotions such as 'body erect' for anger and 'head downward' for disgust. Although Keepon can generate different movements such as rotary motion, up-and-down motion, and linear motion, each motion is limited to its shape. Thus, Keepon is restricted to generate emotional motions of humans.

Emotional motions of Jibo and Tega are similar to emotional motions of humans. Jibo generates human emotional motions by naturally connecting between motions of a head and a body according to "line of action," one of principles used to character design [18]. Tega also produces emotional motions through simulating design concepts by using 3-D animation. Unlike Tega, Jibo can support 'twisting' and 'vibrating' by rotary motion. Through this, Jibo can express disgust and fear with emotional motions. However, Jibo do not support up-and-down motion. Because of this, Jibo is unable to express repetitive up-and-down motion that Tega can represent.

As a result, expression of emotional motions is limited according to an appearance of social robots. To solve this limitation, we need to consider how we can generate diverse movements within a simple shape.

5. METHODS FOR EMOTIONAL MOTION PROTOTYING

In order to provide emotional motions to social robots, this research proposes methods for generating emotional motions in this section. As shown in figure 1, we can implement six basic emotions with movements.

Table 2: The Results of Case Analysis

Case		Keepon	Jibo	Tega
Characteristics		• Mainly body movement, follow up head • Head and body are almost integrated	• Head and body movement • Apply "Line of Action" • Expression through 3-axis cylinder	• Mainly head movement, follow up body • Apply "Squash and Stretch"
Emotional Motion	**Anger**	• Body erect • Moving body backward (Darwin's study)	• Head and body erect • Moving head forward • Vibrating the body (Darwin's study)	• Head erect • Stretch forward quickly (Darwin's and Coulson's studies)
	Disgust	• Moving head downward (Wallbot's study)	• Moving head downward • Twisting body (Wallbot's and Coulson's studies)	• Moving head backward • Crouching (Wallbot's study)
	Fear	• Vibrating the body	• Moving head and body backward • Vibrating the body (Coulson's study)	• Crouching (Darwin's study)
	Sadness	• Moving body side to side slowly	• Moving head downward (Coulson's study)	• Moving head backward and downward • Bending body backward (Coulson's study)
	Surprise	• Rocking the body from side to side	• Moving head upward	• Moving head upward • Bending head backward (Coulson's study)
	Happiness	• Bobbing the body up and down	• Moving head and body backward, and vibrating (Coulson's study)	• Moving body up and down • Moving body side to side quickly

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

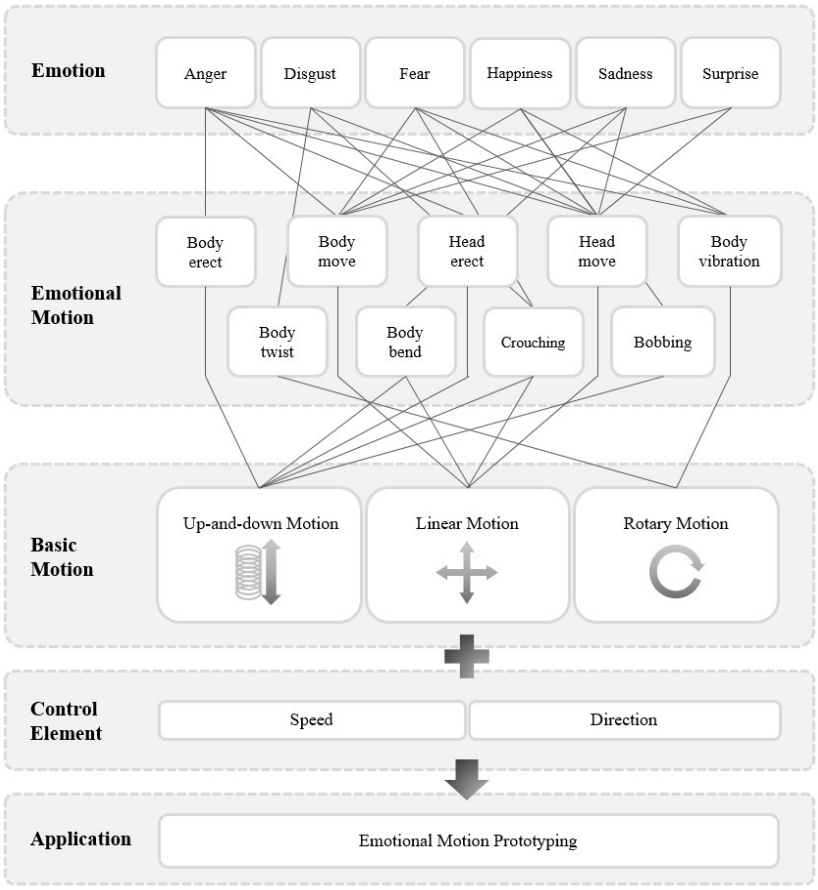

Figure 1: Methods to Express Emotional Motions of a Social Robot

Above all, one of six basic emotions can be selected. After selecting one emotion, emotional motions of social robots extracted from case analysis are confirmed. Emotional motions are constituted based on basic motions that social robots can utilize. Finally, through considering the speed and direction of emotional motions, emotional motions are completed.

For example, emotional motion with "anger" is represented by sequentially applying 'body erect and move', 'head erect and move' and 'vibration.' In order to apply these motions to social robots, up-and-down motion for implementing 'erect' and linear motion for implementing 'move' are required. Furthermore, rotary motion is need for 'vibration.' Final emotional motion is created by adding high speed and backward direction with anger to this combination.

For effectively applying these methods, we considered utilizing the kinematic of a Delta robot because the Delta robot can generate its fast and free motions in a restricted space.

6. WORKING PROTOTYPING

6.1 Delta Robot

It seems that recent social robots focus on the movement of empathy rather than the similarity of human and robot behavior. Therefore, in this research, we develop and implement a prototype that can provide the movement of social robots by utilizing the kinematics of a Delta robot. The Delta robot developed by Reymond Clavel is an "industrial parallel robot" that has "three translational degrees and one rotational degree of freedom" by utilizing "three kinematic chains" and four actuators [19, 20]. The Delta robot has been mainly used for assembling, packaging and picking in factories due to its fast and free motions in a restricted space [21]. It has been introduced to numerous fields since the patents of the Delta robot expire [22]. The Delta robot is applied for developing interactive kinetic media façades [23] and is also being used for developing 3D printers

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[24]. Delta robots can easily produce up-and-down, linear, and rotary motions by moving the end effector with three actuators. The joints connected to each actuator consist of ball joints, which can realize free and dynamic motions. In addition, the Delta robots can generate diverse motions by controlling the angle and speed of the three actuators. Therefore, if the motions of the Delta robot are made into an arm or body of a social robot, rather than a robot arm of an industrial process, it will be able to generate free and dynamic emotional motion. Figure 2 presents the kinematics of the delta robot with four actuators.

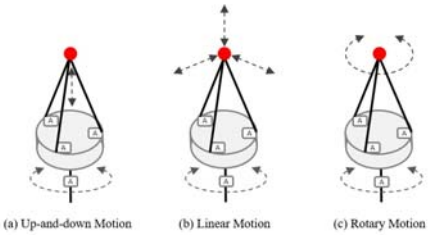

Figure 2: Kinematics of a Delta Robot

6.2 Building Emotional Motions

In this section, emotional motions for six basic emotions were built by combing three basic motions of a Delta robot based on their speed and direction. The built emotional motions will be tested with a working prototype. Figure 3 shows

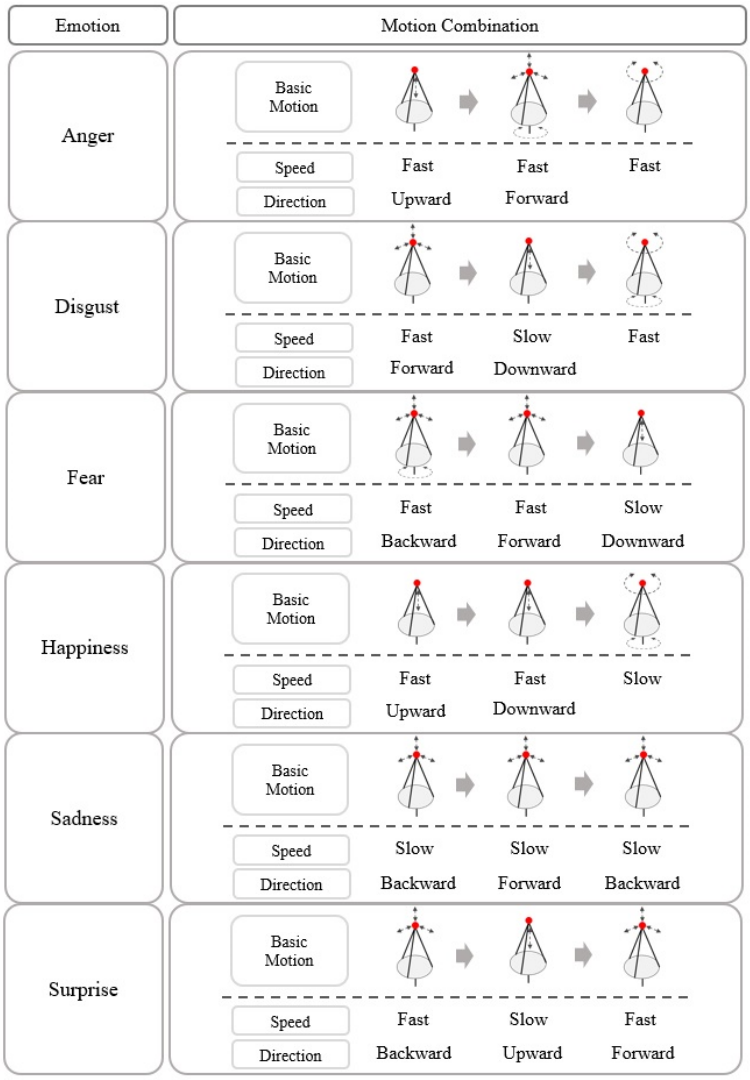

Figure 3: Classification of Emotional Motions Using a Delta Robot

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the Emotional Motions for social robots based on the Delta robot.

6.3 Prototype Structure

In this research, a prototype consists of hardware as a Delta robot that can implements emotional motions and software as a mobile applicaion that controls hardware. The hardware proposed in this research can be considered as a smart, connected device that generally consists of "a physical component", "a smart component", and "a connectivity component" [25]. The physical components are devided into two parts: an upper part and a lower part. The upper part includes three servo motors an 'three kinematic chains' connected to them. The lower part has one servo motor to rotate the upper part. Through using these four servo motors, we can create various movements for social robots.

The smart component of the hardware includes a microcontroller, Bluno Beetle with an ATmega328. This microcontroller functions as processing and storing motion data, which support the Arduino Integrated Development Environment (IDE). The kinematics of a Delta robot were programmed by an author. By utilizing this, we can adjust diiferent angle and speed in order to generate emotional motions that we want.

Moreover, a Bluetooth 4.0 chip as a connectivity component was placed on the microcontroller to connect with software. We can wirelessly control emotional motions by a smartphone. This prototype was developed for concentrating on emotional motion prototyping. Thus, we did not add different sensors to our prototype. Figure 4 presents the structure of the prototype.

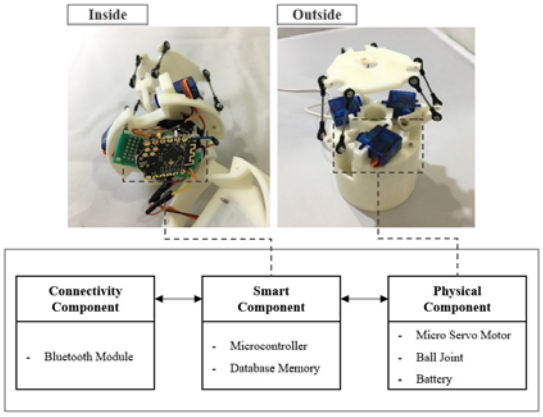

Figure 4: Structure of the Prototype

7. TESTS

The emotional motion of a Delta-robot-based social robot is produced by combining basic motions of an upper part and rotary motion of a lower part based on the speed of the motions. The

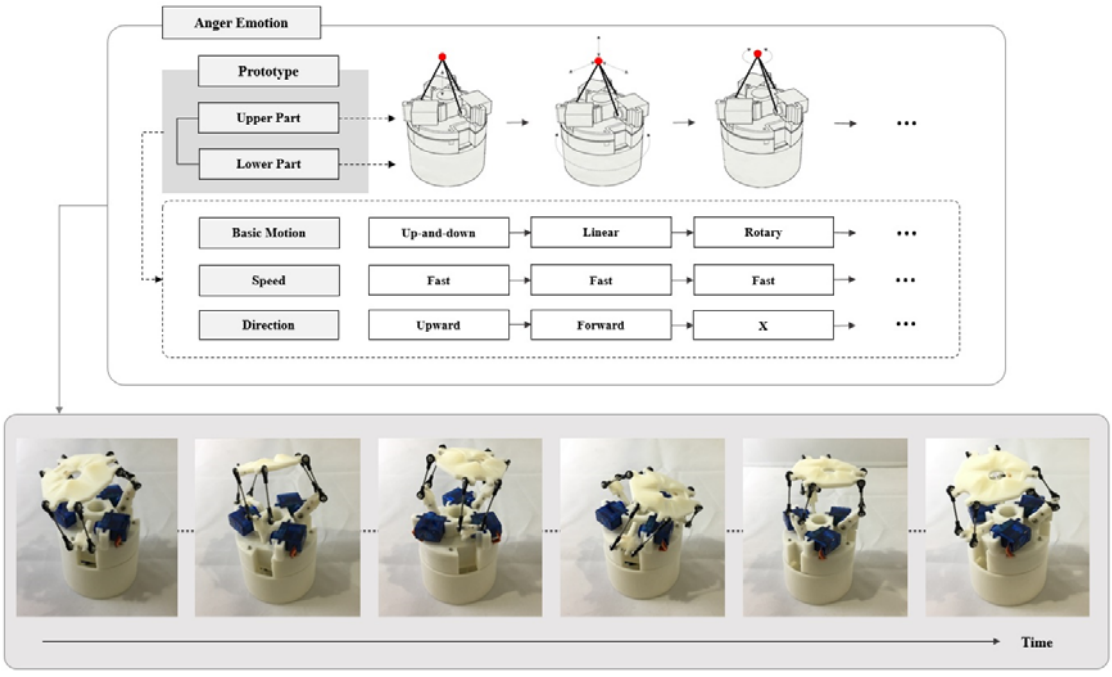

Figure 5: Prototype Test for an Anger Emotion

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

developed prototype was tested based on six basic emotions in this research. Figure 5 illustrates a prototype test for anger as one example. Emotional motions are expressed by changing basic motions and directions within a limited trajectory and speed in terms of time.

We tested emotional motions extracted from case analysis based on six emotional motions that support our prototype. Our prototype was able to express all emotional motions of existing social robots. In addition, our prototype had the potential to expand emotional motions due to being implemented by combining of basic motions of a Delta robot. Moreover, our prototype enables designers and developers to create various emotional motions in limited simple shapes when it is used as a body, a head and arms of a social robot.

8. CONCLUSION AND FURTHER RESEARCH

The purpose of this research was to develop emotional motion prototyping of a social robot utilizing the Delta robot kinematics. For this, this study began by investigating literature related to emotional motion of social robots. Based on these investigations, emotional motions of humans were classified based on six basic emotions. Through this, we were able to recognize limitations of currently developed social robots. Moreover, methods to generate emotional motions of social robots were built and a Delta-robot-based prototype that consists hardware and software was developed and tested.

In this test, our prototype proved to superior to existing social robots in emotional motions since our prototype expressed all emotional motions that existing social robots can express.

In this study, the pivotal findings were: (1) various physical emotional motions can be built by the Delta robot kinematics, and (2) physical emotional motions can be generated by combining several motions with controlling speed and directions.

Therefore, this research will contribute to help designers and developers better understand and further develop emotional motions of a social robot.

The long-term goal of this research is to develop a social robot that supports diverse emotional motions. As the first step for this, this research focused on implementing physical emotional motions with our prototype, providing methods to express emotional motions. Thus, this study has some limitations in that our prototype is not developed as an actual shape of a social robot.

Further research is to develop an actual social robot based on the Delta robot kinematics, applying the results of this research. Further improvement to the prototype would be as follows: (1) designing a shape of an actual social robot in order to applying our prototype to it, (2) developing a web-based Internet of Things(IoT) platform for connecting our social robots, (3) developing effective technology to connect the IoT platform and our social robots, (4) developing multi-directional communication among our social robots via the IoT platform, (5) creating a new smart home service utilizing our social robot, and (6) evaluating user experience(UX) about the service based on our social robot.

ACKNOWLEDGMENS

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2016S1A5A2A03927815)

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