Expression of Emotion and Intention by Robot Body Movement

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Abstract. A framework and methodology to realize robot-to-human behavioral expression is proposed. Human-robot symbiosis requires to enhance nonverbal communication between humans and robots. The proposed methodology is based on movement analysis theories of dance psychology researchers, namely Laban, Lamb and Kestenberg. Two experiments on robot-to-human behavioral expression are also presented to support the methodology. One is an experiment to produce familiarity with robot-to-human tactile reaction. The other is an experiment to express a robot's emotions by its dances. This methodology will be a key to realize robots that work close to humans cooperatively.

1. Introduction

Body movement is one of the most distinctive features of robots comparing other machines. It can be used as a medium to express emotion and intention powerfully, just like pet animals.

The authors have been researching on robots that work close to humans and cooperate with humans[8]. One of the problems on human-symbiosis robots is that humans are very sensitive to robot movement, since they tend to be affected psychologically by robot movement. Consequently, in close interaction with humans, the movement of robots must display correct contents, that is emotion and intention which reflect condition of their system and context of interaction, for example.

Conventional industrial robots, however, communicate with human by using symbols, signs and languages. Those symbolic displays are inefficient and strange to express emotional contents. Some robots in amusement parks express psychological contents, but their movements are fixed because they do not have algorithms to design their body behavior spontaneously.

The authors therefore propose a methodology of robot-to-human expression of emotion and intention with robot behavior.

Studies on nonverbal communication of humans and animals should help make the framework. Both of two major theories, namely Ekman's categorical perspective and Mehrabian's dimensional perspective, are analytic but abstract to implement on robot algorithm. The author use Laban's theory of body movement, for the theory describes body motion quantitatively and covers a wide range of body expression.

In this paper, the authors propose and verify with experiments 1) a methodology to express familiarity in tactile robot-to-human channel, and 2) a methodology to express emotion and intention by showing robot behavior to humans.

2. Principles on Robot Behavioral Expression

2.1. Dysfunction and Function of Robot Behavioral Expression toward Humans.

Humans have a strong tendency to sense and be cued by movements of other people and objects. Getting those signal, you consciously or unconsciously guess inner condition of them and/or their attitudes to you.

In addition, humans have a tendency to personify non-human animals, machines and other objects.

As a result, movements of a robot working close to a human are strong determinants to produce psychological effect and cues to him or her. The closer and more active a robot is, the more important those nonverbal signals caused by the robot body movement is, comparing voices, beep sounds or LED rights emitted by the robot.

In the people's stereotype about conventional robots, robots move their bodies unnaturally and weirdly. Those dysfunction on nonverbal commutation of conventional robots can be classified into 3 type shown in figure 1.

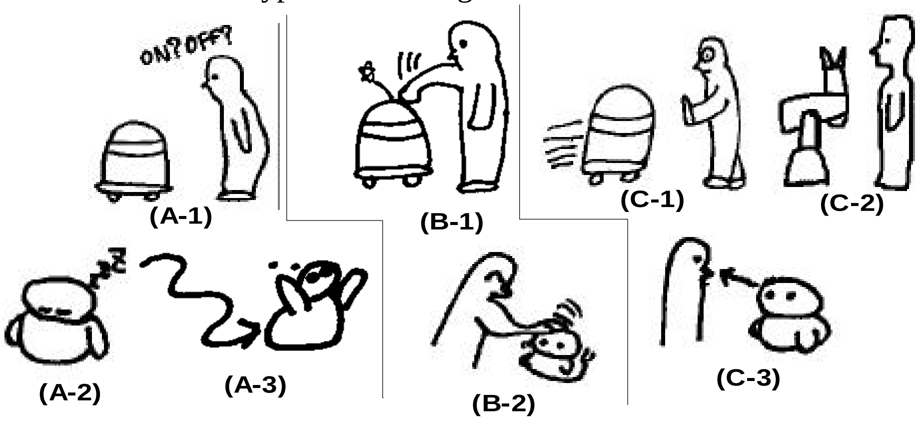


Fig. 1 Examples of Nonverbal Communication between a Human and a Robot

[A] Movement which tells condition: Conventional industrial robots do not reflect their inner condition in their movement. In figure A-1, it is difficult to tell the robot is power-on, out of order and just idling if it keeps stopping absolutely. Using expressive behavior, in contrast, a robot can send information silently, obviously or powerfully. For example, a robot can behave to represent condition, such as idling (see A-2) or emergency (A-3).

[B] Tactile communication: People feel weirdness and unfriendliness when a robot they touched does not make reaction as shown in figure B-1. Since it seems the robot cannot tell tactile information, people may consider the robot is danger because they might be hurt by collision with it. On the other hand, familiarity of a robot can be produced in tactile communicational channel. In figure B-2, a robot is responding a human's touch behavior to produce familiarity just like a pet.

[C] Eye contact: Eye contact is one of the most powerful nonverbal methods, because you usually use eye contact method to tell somebody's attention and attitude toward you. This method is easy to implement for robots, and actually some robots in amusement parks use it to express attention as shown in figure C-3. When a robot does not have eyes, it is very inconvenient. For example, you cannot tell whether the robot in figure C-1, which is running toward you, knows your position or not. You may feel weirdness to talking with a eye-less robot as shown in C-2.

The summary is that for realization of robots that work close to or among humans, the nonverbal communicational functions of robot described above must be enhanced.

2.2. Communicational Channels and Labanian Theory on Body Movement Expression

Before to describe about theories, the authors should classify nonverbal communication in respect to contents and ways of expression as shown in table 1.

Table 1. Channels and Methods for Robot Body Expression

Content to be Expressed	Channel	Method
Familiarity	Tactile	Passive *Effort* and Rhythm Contact Reaction
Inner Needs and Distress	Tactile	Aggressive *Effort* and Rhythm Contact
Other Inner States and/or Attitudes to People and Things	Visual	Eye contact, Posture and Dance

2.2.1. 'Effort' *and* 'Shape': *Factors of Impression on Visual Body Expression*

The lower-most line of table 1 says that a robot in the future may express humans certain kinds of information on its inner condition and attitude toward humans by using showing glance, posture and body movement.

To realize behavioral expression function of robots, it is required to construct a theory that **1)**describes body movement quantitatively, and **2)** provides algorithms which translates psychological contents into body movement. The authors employ the body expression theory made by R. Laban[3] and his successors, namely Lamb, Bertenieff[4] and Kestenberg[5]. In this paper, the theory is called Labanian theory.

Labanian theory classifies element of expression contained in body movement into 2 categories, that is *Effort* and *Shape*.

Effort is defined as qualities of movement. *Effort* has 4 elements and each of them has bipolar feature between fighting versus indulging. The idea of assuming bipolar structure for animal behavior comes from Darwin's theory[1].

Table 2. Elements of *Effort* and their Mechanical Realization

Indulging *Effort*	**Fighting *Effort***
Indirect *Space Effort*	**Direct Space Effort**
Bend elbow and knees.	Make limbs straight.
Move limbs around body.	Move limbs straight from body.
Light *Weight Effort*	**Strong *Weight Effort***
Small momentum.	Large momentum.
Move only the ends of limbs.	Move body together.
Sustained *Time Effort*	**Sudden *Time Effort***
Continuos movement.	Change movement suddenly.
Low tempo.	High tempo.
Free *Flow Effort*	**Bound *Flow Effort***
Smooth curve trajectory.	Zigzag trajectory.
Low dumping and low brake.	Kill inertia.
Function cooperative actuator.	Function antagonist actuator.

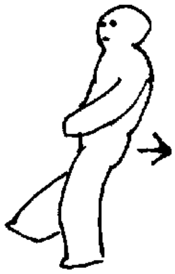
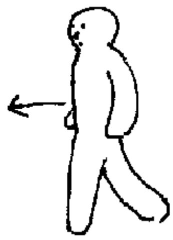
As shown in table 2, the 4 elements of *Effort* are named as *Space, Weight, Time* and *Flow.* _The authors propose mechanical realization method of each of *Effort* elements as describe self-explanatory in table 2.

1) *Space Effort* is directivity of posture, movement and glance. To control it, shape and trajectory of limbs should be controlled. **2)** *Weight Effort* stands for strength and power of movement. To control it, momenta that robot body parts have should be controlled. **3)** *Time Effort* is the feature of urgency versus calm. This can be controlled by managing tempo of dance and speed of motions. **4)** *Flow Effort* stands for carefulness versus easiness that can be seen in movement. This can be controlled by managing continuity of the trajectory of movement and functioning cooperative or antagonist actuators.

Shape is feature concerning overall posture and movement. In this paper, the authors employs one of *Shape* frameworks named *2-dimential Shape* shown in table 3, since *2-D Shape* has rather clear relationship to psychological condition of the mover.

Two-D *Shape* stands for extent or slant of posture and movement on 3 imaginary planes, namely *Table, Door* and *Wheel planes*.

Table 3 *Shapes* of Body Movement and Consciousness Expressed

Plane of Movement	*Table*	*Door*	*Wheel*
Consciousness	Attention	Intention/Dominance	Decision
Effort Dominance	*Space*	*Weight*	*Time*
Figures of *Shapes* relevant to Excitement	 Concentration of Attention	 Intent/Dominance	 Surprised
Figures of *Shapes* relevant to Indulgence	 Exploring/Searching Diffusion of Attention	 Obedient/Submission	 Confident

Labanian theory says each plane has affinity to particular *Effort* element which is written as *Effort* dominance in the table 3. This means if you move your body in one of the planes, the corresponding *Effort* dominance often (but not definitely) becomes obvious in your movement.

1) <u>*Table plane*</u> is the horizontal plane which goes through at waist. *Shape* on *Table* Plane is defined as extent/concentration of posture and movement on the plane, and expresses psychological condition about attention toward people and objects. **2)** <u>*Door plane*</u> is the vertical plane which divides front and back. *Shape* on *Door* Plane is defined as slant of posture and movement on the plane, and expresses psychological condition about activeness and dominance of the mover. **3)** <u>*Wheel plane*</u> is the vertical plane which divides right and left. *Shape* on *Wheel* Plane is defined as slant of posture and movement on the plane, and expresses psychological condition about confidence versus astonishment of the mover.

Based upon Labanian theory of *Effort* and *Shape,* a robot can express its emotion and intention by translating them into movement in the relationship between 2D-*shape*, *Effort* and psychological state.

2.2.2. *Message Carriers on Tactile Channel:* 'Effort' *and Rhythms of Muscle Contraction*

The contents expressed via tactile communicational channel are 1)inner condition of the touched person, and 2)attitude of the touched person toward the touching person, such as familiarity.

Labanian theory mentions *Effort* and tension rhythm of muscles carry message. Kestenberg[5] gives an example; when a baby feel inner needs or discomfort, he moves in specific rhythm of shrinking so that he gives his mother impacts as an alarm.

Familiarity, on the other hand, is produced in tactile interaction by reacting passively. M. Fox[6] reported that a wolf behaves passively to his friend wolf in order to express familiarity.

The authors consider that a robot can express inner needs and familiarity via tactile communicational channel.

2.3. *A Scheme of Realization Behavioral Expressive Robot*

2.3.1. *Hardware*

The authors consider 2D-*shape* as important and useful to synthesis bodily expression of robots. Therefore a robot should have structure with which the 3 planes suit, and mechanism to operate 2D-*shape*. Having eyes is also important.

2.3.2. *Software*

Body movement controlling software for robot should be realized as follows:

1. Translation function from psychological contains to body movement. The authors employ the Labanian framework.
2. Efficient notational system for storing and editing body movement. The authors invented *Behavioral Score* that is a notational system for body movement and executed by a LISP program.
3. Function to avoid mannerism. Randomness in the algorithm is required for long-term interaction between a human and a robot.

3. Experiment A : Familiarity Producing with Robot-to-Human Tactile Reaction

3.1. *Hypothesis to be examined*

This experiment verifies hypothesis that passive tactile reaction produces familiarity to a receiver.

3.2. *Experimental Method and Procedure*

The stuffed robot shown in figure 2 is used as the experimental equipment. This robot has a servo motor which is controlled by a computer. The motor can drive the robot's head lengthwise. Tow tactile sensors are embedded in the forehead of the robot so that the computer can sense touches of subjects.

In the beginning of the experiment, the robot continues to move head up and down. A subject shows it for a while and is instructed to touch the forehead of the robot.

The robot changes its movement when it is touched. Three reaction patterns shown in figure 2 are prepared.

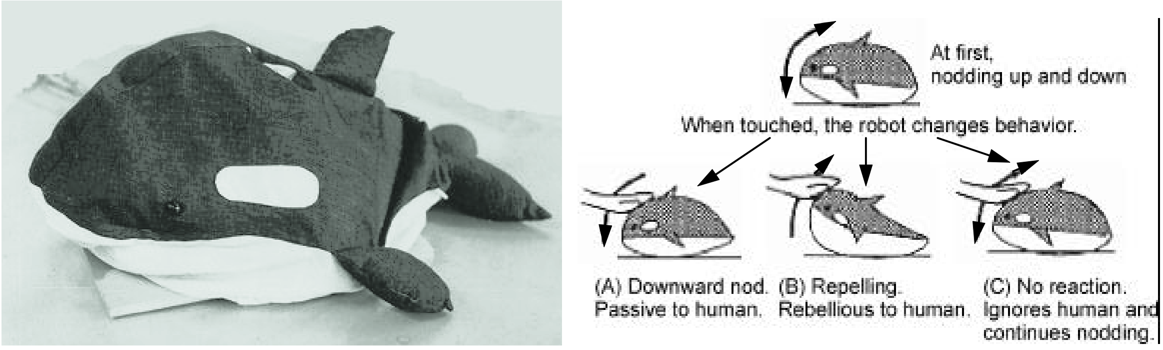


Fig. 2 Experimental Robot and its Reaction when it is Touched

In pattern A, the robot nods down and keep head down until the subject takes his hand off the robot. This reaction consequently is passive to subject's hand movement. We regard pattern A as a passive tactile reaction. Pattern B is designed as the contrast reaction of pattern A. In this pattern, the robot moves its head up quickly when it is touched, so that the subject feels some impact. We regard this pattern as a repelling tactile reaction. Pattern C is designed for comparison to Pattern A and B. In pattern C, the robot does not changes its behavior even if it is touched.

Each subject experiences each of 3 reaction pattern. After a subject touched the robot and see each reaction for several times, the subject judges the impression caused by the reaction. Impression is measured by using semantic differential (SD) rating method. Each SD measure has 7 points, namely 'no judgment'(0) in the center of the measure, and 'slightly' (+1, -1), 'fair' (+2, -2) and 'very' (+3, -3) in both side of the measure.

We actually measured 5 pair of impressions. However we can show 2 detailed result of them as follows because of the shortage of the space.

Question 1: "Do you feel the robot has goodwill or hostile feeling toward you?"

Question 2: " Do you think the movement of the robot is an expression of some intention?"

The SD scores are processed by statistical t-test, so that we can get statistically significant impressions. The significant level is 5%.

3.3. Results

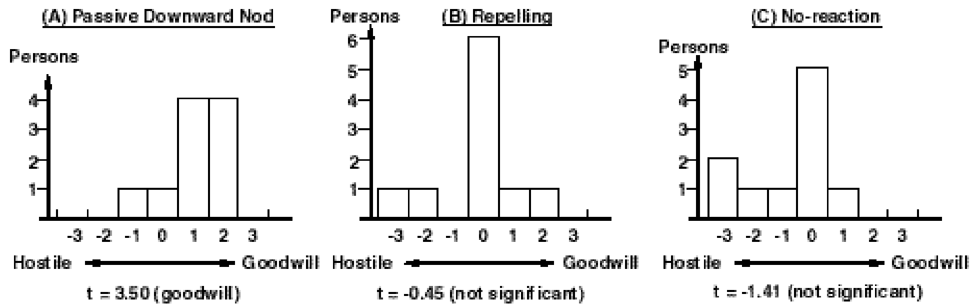


Fig. 3. Semantic Differental Rating Result on Famiriality Produced by the Robot Reactions

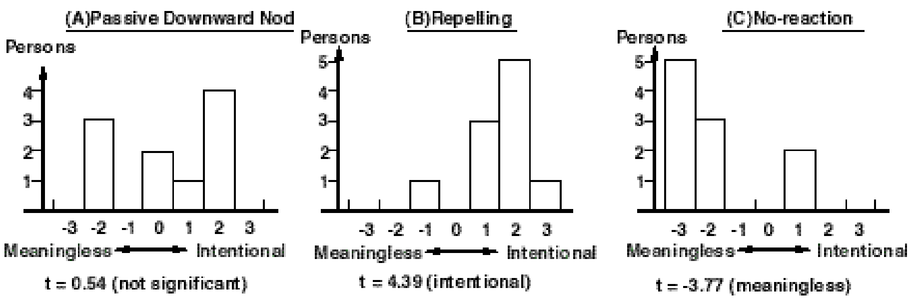


Fig. 4. Semantic Differental Rating Result on Intentionality Produced by the Robot Reactions

The total number of the subjects is 10. Figure 3 shows the SD scores of familiarity produced by each robot reaction. Passive reaction pattern A got significant result in familiarity. Pattern B and C did not get significant result. Figure 4 shows the SD scores on intentionality produce by each robot reaction. While pattern A did not get significance, we can conclude that pattern B seemed a behavior with some intention and pattern C seemed meaningless behavior.

Other significant results must be describe briefly. Passive reaction produced tamed impression. No-reaction (pattern C) produced machine-like impression and seemed danger.

3.4. Discussion

The result on familiarity of passive reaction is in agree with the hypothesis described in section 3.1. In other words, we can conclude that passive tactile reaction produces familiarity.

Reaction pattern B produced intentionality. According to Kestenberg's theory, impacting tactile signals express alarms of a baby to her mother, for example. Therefore we can used robot's impacting tactile reaction as an alarm toward a human.

No-reaction (pattern C) produced bad impressions. Most of conventional robots do not react when their bodies are touched. This means that we cannot make home-assistant robots, for example, which can make communicational harmony with humans unless we make tactile communicating function of robots.

4. Experiment B : Expressing Robot's Emotional State with showing Postures and Body Movements

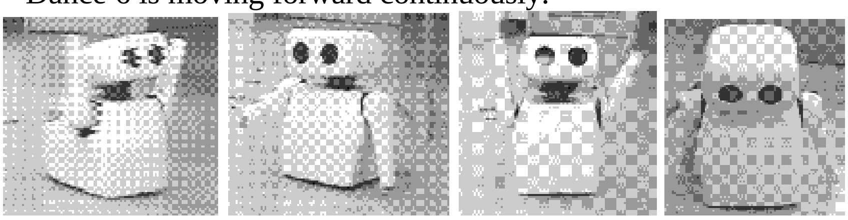
4.1. Purpose

Basic idea is that an experiment must be done to verify Labanian principles. However, there is a too large number of combinations of behavioral elements to verify all principles. So we design 6 experimental dances of the experimental robot. Emotional impressions expressed by each dance are measured and compared with Labanian principles.

4.2. Experimental Method and Procedure

The experimental robot shown in figure 5 is designed only for dancing. It has 2 wheels in the bottom, 2 one-DOF arms and a head which can move in roll, pitch and yaw.

The experimental dances are written in *Behavioral Score*. See [7] for detail. The robot is controlled by a personal computer. Dance 1 is turning with raised arms. Dance 2 is moving forward and backward and raising and lowering an arm. Dance 3 is raising arms and the head and withdrawing intermittently. Dance 4, 5, 6 are lowering arms and drooping the head. Dance 4 is moving back continuously. Dance 5 is, in contrast, intermittent. Dance 6 is moving forward continuously.



(Turing Movement of Dance 1) (Raising Arm Movement of Dance 2) (Most-used Posture of Dance 3) (Most-used Posture of Dance 4, 5, 6)

Fig. 5. Experimental Robot and Still Images of Experimental Dances

Table 4 tries to describe features of the 6 experimental dances. Cells written in bold stand for they are characteristics of each dance. *Shapes* and *Time Effort* can be judged objectively for they are substantial compared to other factors.

A subject is shown each of 6 dances and judges emotion of the robot. Intensity of expressed emotion is also judged in 4-point SD rating, i.e. from 0 = "no impression" to 3 = "strong emotion".

Table 4. Dance shown in Experiment and their *Shape*, *Effort* and Impression

Dance #	*Shape*			*Effort*				Emotion felt by the subjects			
	Movement on floor	Face & arms	symm. of arms	Time *Effort*	Weight *Effort*	Space *Effort*	Flow *Effort*	Joy	Astons	Sad	Anger
1	**turn**	**up**	sym.	Contins	Strong	Indrct	Free	**15**	5	0	2
2	**frwd & bck**	hrzntl	**asym**.	**Sudden**	Strong	Direct	Bound	0	2	0	**5**
3	**back**	**up**	sym.	**Sudden**	Neutral	Direct	Bound	0	**10**	0	0
4	back	**down**	sym.	**Contins**	Light	Direct	Free	0	0	**16**	0
5	back	**down**	sym.	**Sudden**	Neutral	Direct	Bound	0	0	**13**	0
6	**forward**	**down**	sym.	Contins	Neutral	Direct	Bound	0	0	**14**	3

4.3. Results

The number of the subjects is 10. The sums of answered points are shown in the right part of table 4. Dance 1 expressed joy. Dance 2 slightly expressed anger. Dance 3 expressed astonishment. Dance 4, 5 and 6 expressed sadness.

4.4. Discussion

Regarding *Door plane*, *Shapes* are in low position (dance 4, 5 and 6) expressed sadness which is related to less intention or submission. This fact agrees with Labanian theory.

We succeeded to express joy, astonishment and sad with robot body movement. Although it is hard to compare among other result of dances, the authors found Labanian schema can be used as efficient guide for designing robots' behavioral expression.

5. Conclusion

Regarding the importance of nonverbal communication of robots that work close to humans, the authors proposed a methodology for mechanical realization of expressing emotion and intention. The methodology is based upon Labanian theory, which deals with body movement quantitatively. Two experiments were done to implement and verify the methodology. In future works, the authors will apply the generation of robot behavior for long-term human-robot-symbiosis.

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