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Estimating Emotion with Biological Information for Robot Interaction

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Abstract

To estimate emotion is difficult, not only for others, but even for people themselves. However, this is important for robots of the future, that are expected to operate in harmony with humans. This study proposes a method of estimating emotion using involuntary biological information. To be able to estimate emotion and feeling, a lot of work has been done in the field of artificial intelligence and robot engineering that focuses on human robot communications, especially where it applies to therapy. Generally, estimating emotions of people is based on expressed information such as facial expression, eye-gazing direction and behaviors that are observable by the robot. However, sometimes this information would not be suitable, as some people do not express themselves with observable information. In this case, it is difficult to estimate the emotion even if the analysis technologies are sophisticated. The main idea of our proposal is to use biological information, brain waves and heart rate for estimating the actual emotion of people that is the result or the nonconscious brain. The first experiment shows that our suggested method will outperform the traditional method, for the people who cannot express emotion directly. And, after changing the technique that measures the degree of joy for each scene and compared it with the subjective evaluation, the second experiment was performed. In the second experiment, accuracy did not change, but accuracy differed greatly for different people. In the analysis, we have found that there is a correlation between parts of the personality and the accuracy of results.

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1. Introduction

Estimation of emotion is one of the major interests amongst robotics interaction development researchers. Extensive research has been carried out to this end, especially focused on extracting the rules and features of expressions such as user's eye-gaze direction [1], head position, facial and mouth expression [2] and behaviours [3]. These approaches use observable symbols that people can detect with their senses (sight, hearing, touch, etc.) to estimate emotion. However, the limitation of these approaches is that it is difficult to apply them when facial expressions or words and emotion differ from the norm. For example, people can fake a smile when feeling angry inside. In psychology, researchers consider that emotions are sometimes not expressed, and information that is expressed - such as facial expressions, voices and emotion - can differ from the true emotion. This has been widely recognized in psychology [4]. Our research is based on this understanding and aims to understand true feelings. To estimate emotion, we use biological information such as brainwaves and heart rate. Brain wave biological information is collected by EEG (Electroencephalography), which refers to the recording of the brain's spontaneous electrical activity over a period of time. These days, this method is used for in cognitive science and psychology to show different areas of human cognitive activity. Heart rate also will be recorded since it is influenced by central factors through sympathetic and parasympathetic nerves that come from the recognitions of the brain. This biological information can be used to measure human conditions such as being excited [5], stressed [6], concentrating [7], and relaxing [8]. In particular, for emotion, based on the Circumflex Model of Russell [9], by using biometric information, various studies have performed human emotion estimation, and reported that certain evaluations can be made [7]. However, in those studies, the engineering implementation methods and algorithms have not been sufficiently presented. The purpose of this study is to present an algorithm for the psychology model to separate the symbols and feelings, to estimate emotion with the biological information from the proposed method, and to complement it with brain waves and heart rate. The implemented system and planned experiments are intended to provide an algorithm and evaluation method for the accuracy of emotion estimate. Since the evaluation is the result of the limited method presented in this research, it is necessary to experiment by increasing the number of subjects in the future.

The structure of this paper is as follows: In Section 2, we propose the emotion estimate method; in Section 3, we propose the first experiment and evaluation; in Section 4, we propose the second experiment and evaluation; in section 5, we present a discussion.

2. Estimation Method with Biological Information

2.1 Issues and Objectives

As we described in the introduction, we embody the technique that estimates emotion by using biological information. Firstly, we try to separate an emotion into information that is expressed externally, and interior information, in accordance with the psychological classification [4]. The expressed information, we call symbolic information that people use in communication such as words, voice and facial expression. On the other hand, the interior information we call emotional information that is internal. Without taking into account physiological phenomena such as breathing, pulse and blood pressure, it can be difficult to understand the state of the person. These biological signals have been used in areas such polygraph testing [10]. This is something that detects a number of physiological phenomena such as electrical and physical signals like breathing, pulse, blood pressure, etc. However, there has not been enough research on estimating emotion through using direct biological information from the person. The purpose of this research is based on the separation of the symbolic and emotional in psychology, and an object is to present an algorithm using biometric information such as brain waves and heart rate to speculate the person's emotions. With this proposed method, we will achieve an accurate estimation by integrating symbolic and biological information. The robot system is shown in Figure 1. The figure shows that the sensors read the biological information from the human beings, and the robot estimates the emotion using symbolic and emotional values.

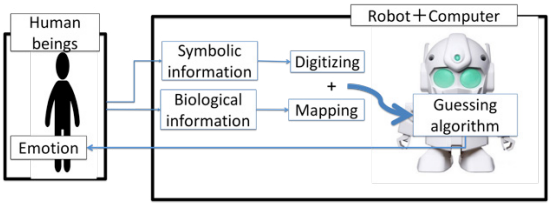

Figure 1. Example of the expected operation of the robot

Table 1. Definition of emotional and symbolic information

	definition	Information used in estimation
Symbolic	Easy-to-read information, read objectively by others	facial expressions, language, voice, etc.
Emotional	Difficult to understand objectively by others, interior information	heart rate, brain waves, etc.

2.2 Symbols and Emotion Classification

In our method, we define the symbolic information and emotional information first. Symbolic information is defined as that which can be easily read by the five senses. On the other hand, emotional information is defined as that which people can hardly read using the five senses (Table1). Symbolic information is standing on the premise that language and culture are shared and you can read signs of emotion to some extent from such words and expressions. Also, with the emotional information, it does not matter whether you know the person or not. Secondly, we defined the emotional information that is difficult to understand by others objectively, interior information. Not only for others, but also for the people themselves, it is difficult to understand correctly. We considered using some signal to express the unconscious behavior of the people to understand emotion objectively. There are lots of approaches to use unconscious expressions such as user's eye-gaze direction [1], head position [2] and behavior [3]. However, these approaches include some intentional behavior of the people. Sometimes people could control these signals intentionally. We consider it difficult to separate the intentional from the non-intentional. Biological information such as brain waves and heartbeat are some of the best signals that cannot be controlled by people intentionally. It is the physical activity of the people. Even if it would include some activity to control emotion intentionally, we could carefully collect the first emotional impression with some method. In physiology, it is known that when emotional behavior occurs, the activity of the sympathetic nerve is enhanced, so we thought it would be possible to estimate emotions.

2.3 Method to use Russell's Circumflex Model

Based on this idea, we use biometric information to estimate emotion. We use an approach that is proposed by Russell [12]. Russell's Circumflex Model is known as a structure to classify emotion. In this research, for the classification of the emotion, the data obtained by the brain wave and pulse are mapped onto a two-dimensional plane of Russell's Model (Figure 2), allowing for the identification of emotion. This method has already been presented in the research of Sakamatsu [11], Yamamoto [12], Hayashi [13], et al. Yamamoto, et al., saw that being relaxed or tense will appear due to a change in emotional information by communicating with the autonomic nervous system, and proposed an analysis technique that measures per the model. In this paper we show that excitement and tension increases the heart rate, and skin temperature rises due to the contraction of the blood vessels. On the other hand, it has been shown that parasympathetic acting upon relaxation reduces heart rate, and dilates blood vessels. In addition, Sakamatsu shows the state of the autonomic nervous system corresponding to the degree of concentration by Russell's Circumflex attention and meditation by brain wave a portion corresponding to the awakening degree of the model in the vertical axis.

Russell's Circumflex Model basically uses biological information from brain waves and the heartbeat. Brain waves show the attention and meditation of brain based on the theory of brain signal analysis on horizontal axis maximum and minimum. Heartbeat shows the pleasant and unpleasant (miserly) mapped to the vertical axis, where pleasure is shown when the heart rate is high, and the unpleasant (miserly) is characterised by a low heart rate.

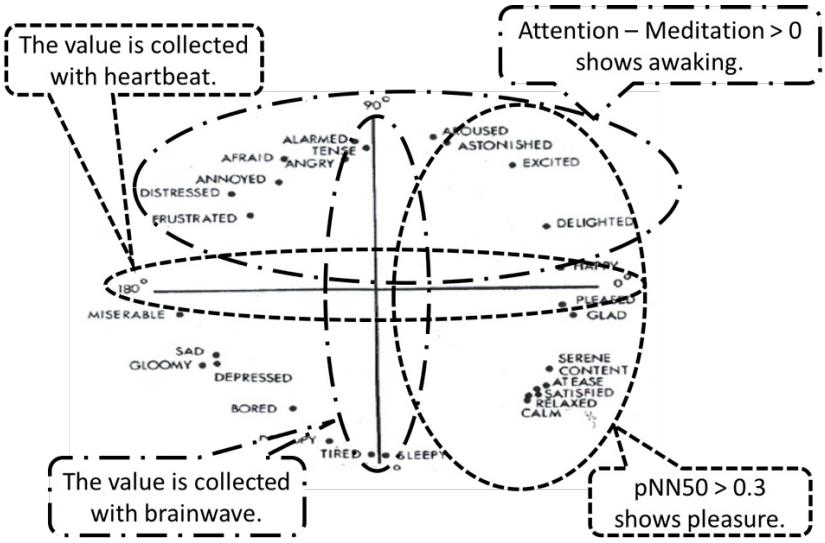

Figure 2. Russell's Circumflex Model [9]

Mapping the biological signal information to the emotional model in the two-dimensional coordinate axis is currently used in engineering research to judge the human condition and emotion and is applied to industrial design of objects such as chairs, and air-conditioners, etc. Sakamatsu uses this model and applies it for overcoming depression by using feedback from the emotion of the person who suffered the depression [14]. In this research, they recorded brain waves with a headband [14], and the value of attention and meditation from zero to 100. Skamatsu's research also uses pulse as value for the x-axis in Russell's Circumflex Model. They use the pulse rate over a one minute interval [11]. We consider one minute as being too long for estimating emotion since we apply it for the interaction with a robot. It is necessary to reduce the time of the judgment for the future application of the robot to achieve this, so we used pNN50 instead of Sakamatsu's pulse judgment method. Regarding pNN50, Takeda describes that the pulse interval has less fluctuation and time lag than LF / HF, which is similarly indicative of pleasant-discomfort [15]. From that, we consider that pNN50, which is obtained from the pulse interval, could stably measure uncomfortable conditions including tension and stress in the 2nd and 3rd quadrant of Russell's model when associating the heart rate index with the x-axis of the model. The measurement time and interval of pNN50 is shorter than the one minutes, and it is widely used to measure heart rate variability (HRV)[13]. The total data processing procedure of estimating emotion using biometric information in this research is organized as follows.

(1) Calculate pulse from the pNN50 from the sensor
(2) Calculate the degree of awakening by the value obtained by the operation of the brain waves
(3) Use both values in (1) and (2) to estimate emotion

2.4 Detailed Method for measuring Heart Beat and Brain waves

In this section, we will describe the detailed method for the calculation of the heart beat and brain waves in judging emotion.

1) How to measure the pleasantness for the X-axis

In the judgment of the pleasantness, we use the pulse analysis method named a pNN50 [16]. Determination of pNN50 is as follows: Firstly, we measure and record the pulse. A pulse is defined as Hbt (heartbeat), and the n-th heartbeat is described as Hbt_n. Between the two pulses, we can observe the interval for each. In this paper, we define the interval as Diff. The n-th number of the Diff is described as $Diff_n$ Then, the 30 pieces of pulse interval Diff is described as $Diff_0 = |Hbt_1 – Hbt_0|$, $Diff_1 = |Hbt_2 – Hbt_1|$, … $Diff_{30} = |Hbt_{30} – Hbt_{29}|$. After that, the 30 pieces of 50 ms or more, the ratio of the Diff is calculated (the number of the number / Diff of 50 ms or more of Diff), the value of the ratio and pNN50 [16]. This value is determined to be pleasant, the higher it is in the index of Pleasant - unpleasant. In order to deal with the value of the pNN50 as the value of the X-axis of Russell's Circumflex Model,

we decided on a reference point. We have a value that becomes the point of origin 0.3. Since the standard value of pNN50 is 0.3 [17]. Originally, if the focus is on real-time, the accuracy is reduced, or to guarantee accuracy, real-time is reduced. It is trade-off requirement. In this research, we use pNN50, satisfying the real-time requirement without reducing accuracy. Brain wave sensors used in this research implemented an algorithm that calculates the attention and meditation at a level from zero to 100.

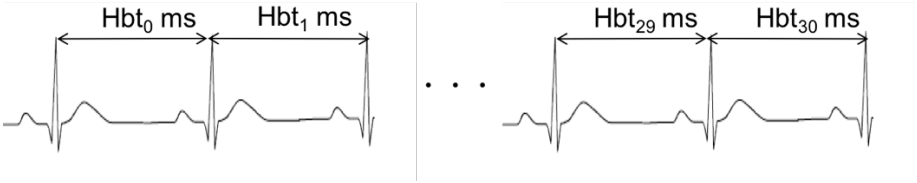

Figure 3. pNN50 pulse interval

2) How to measure the pleasantness for the Y-axis

In this research, the value of the Y-axis of the Russell's Circumflex Model is "Attention-meditation" ([11] reference). This value is referred to as an awakening degree. Awakening degree is -100 (attention: 0, meditation: 100) ~100 (attention: 100, meditation: 0). In Russell's Circumflex Model, an awakening degree at the origin or zero means attention = meditation. Based on the calculation of biological information such as heartbeat and brainwave, we apply Russell's Model to estimate the emotion. Using these parameters, we determine that the "joy emotion" in the case that awakening degree is 0 or more and pNN50 is 0.3 or more.

3. Preliminary Experiment

3.1 Objective of the Experiment

In this research, in order to know the effect of our approach, we compare the two methods. One is to use biometric information for estimating emotion, which is our proposed method, and the other is to use only the symbolic information, as used in the other approaches. For the judgment of the latter, we use an existing determination algorithm such as face recognition, since the analysis of symbolic information is not the purpose of this research. Facial expressions recognition is one of the most popular methods used to judge the emotion using symbols that are expressed, and recognized objectively. It is suitable for our definition of the symbolic information.

For the judgment of emotion by the facial expression, we use Omron's OKAO VISION [18]. It uses the image processing technology to analyze the face, and classify the face to the five types of facial expressions (Surprise, Anger, Natural, Sadness, Happiness). We quantify the current facial expression from a string that shows a log of the facial expression (Happiness → 5, Angry → 2, Sadness → 4, Natural → 3), which will be passed to the algorithm, which in turn will be described later. Facial expression and emotion in this research correspond to the decision of OKAO VISION as shown in Table 2.

Table2. Correspondence of the judgment in the actual emotion and the determination with the parameter

Decision of OKAO	Happiness	Angry	Sadness	Natural
Decision of emotion	Joy	Angry	Sad	Comfort
Numeric value to pass	5	2	4	3

3.2 Experimental Method and Evaluation

We compare the OKAO VISION result and proposed method with the experiment. In this experiment, we firstly focused on the emotion of "joy", since we consider it easier to set up the artificial experiment environment to evoke this emotion than other emotions. To measure the biological information we use Neuro sky's Mindwave Mobile [14] for the collecting data of the brain waves, and a Arduino heartbeat sensor [19] from the Tokyo devices company to measure the heartbeat.

3.3 Procedure

The preliminary experiment is executed with the two collaborators (a 21- and a 23-year-old man). The experiment was carried out in the laboratory and, in order to realize the goals of the robot study, we implemented the reaction operation on the robot using the Rapiro[20] for the feedback interface of the result. Determination of the reaction operation compares the emotion determined by expression and biological information. If they were different, the robot swung its hands and face to the side as if to deny. On the other hand, if they were the same, the robot raised one hand as to rejoice.

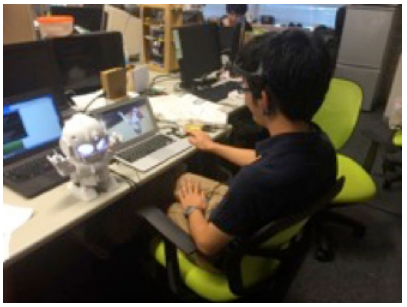

Figure.4 situation of the experiment

The experimental procedure is as follows:
(1) To evoke the emotional of "joy", the collaborator of the experiment searches for an interesting video [13].
(2) The collaborator watches the video.
(3) The facial expression mechanism and biometric information mechanism collect the information of collaborator with the sensors (camera, brainwave and heartbeat measuring instrument.
(4) The facial expression mechanism and biometric information determined whether the emotional of "joy" on the basis of the "emotional decision algorithm".
(5) Facial expression emotion and biological information are compared, and fed back to the robot operation.
* 3-5 are repeated each second between the videos.

3.4 Evaluation Method

In our experiments, we analyse the result using an evaluation index. The Mean of Absolute Error (*MAE*) was adopted to use the broadest value as an index to measure the accuracy. We compared the *MAE* f symbolic information using the pulse and heart rate and biological information using facial expression. The formula for the *MAE* is defined as follows.

$$MAE = \left(\frac{\text{Number of determinate emotion while watching the video} - \text{Number determined that the "joy"}}{\text{Number of determinate emotion while watching the video}} \right) \times 100$$

Table 3. Result of the First Experiment

	Facial expression (*MAE*)	Biological information (*MAE*)
Collaborator A	0	28
Collaborator B	100	25
Average A,B	50	26.5

3.5 Result of the Experiment

We describe the result in this section. The result is shown in Table 3. The two collaborators are listed in the first column, then the two methods are listed. As collaborator A watched the video, the facial expression mechanism judged his emotion as "joy" for the whole time during the video playback, therefore, the value of the *MAE* became 0. In contrast, the biological information, *MAE* resulted to 28. Since the *MAE* is an index that shows difference of actual emotion and estimated emotion, it means that for collaborator A, the estimation works better judging the facial expression than the biological information. On the other hand, in Table 3, the result of collaborator B shows a

contrasting result to that of collaborator A. In the facial expression, *MAE* shows 100. It shows the highest difference of the actual emotion and expressed emotion of joy on the face. It means that the collaborator did not show any facial expression of joy, so the difference of the judgment is high. We asked both collaborators if they are expressive or not. A is very expressive and B is not expressive of their emotion in usual communication. Overall, the average *MAE* of the two collaborators was facial expression 50, and biological information 26. In the emotion of "joy", biological information is better than symbolic information. Taking the simple average, our proposed mechanism would be effective for people who are not expressive, however, it will be less effective for people who are expressive. There are issues here and the analysis method should be improved.

3.6 Problems and Issues

The preliminary experiment showed that it is necessary to improve the proposed method to estimate emotion. We consider the following issues and improvements for achieving the experiment's purpose.

1) Pulse sensor and pNN50

In our experiment, one of the reasons that the estimated rate was not high, would come from the hardware. The pulse sensor we used was not sensitive; the data contain a lot of noise, and did not obtain an accurate value of the pulse interval, decreasing the estimated precision of pNN50. If the number are less than the ten, the result was considerably worse. Therefore, we will try to select a more sensitive sensor that can obtain the number of value 30 would be obtained.

2) Experimental procedure, place, method improvement

The procedure should be carefully prepared to collect the biological information. The procedure influenced the results greatly. We found that the results changed when the collaborator took a rest after the experiment. This means that without the rest, the result of the brain wave experiment fluctuates. Therefore, we will let the collaborator rest for two minutes between experiments next time. Moreover, the evaluation method should consider the relative nature of the biological information, since the biological information depends deeply on the person, and is influenced easily by their environment, within the short period. The preliminary experiment was executed in the laboratory that has many people talking and other noise. This may have disturbed the concentration of the collaborator during the experiment. So we consider it necessary to change the experiment to where the collaborator can concentrate better on the video. In the experiment, we prepare a robot to view reaction behaviors of the collaborator with the changing of their biological and symbolic information while watching the video. It may disturb the collaborator's concentration for recognizing the contents of the video. This study aims to establish the method of estimating emotion so next time it would be better not to use the robot.

3.7 Problems and Improvements

To further increase the accuracy of preliminary experiment, we would try to improve as follows: We focused on the characteristics of biological information that changes within a very short time. To grasp the nature of the status of the emotion with the biological information, we need to re-consider the experimental environment, procedure and evaluation method. For the experimental environment, we should prepare a quiet place to encourage concentration, and for the procedure, we should include a rest between the operations and experiments for the collaborator. For the evaluation method, we re-considered the calculation and procedure of the preliminary experiment. In the preliminary experiment, we only considered the average score of the biological information using the total video watching time. However, it would be difficult to identify the point that changed the biological information significantly. To solve this problem, we will divide the sections of watching video for each scene, and we will evaluate the degree to how much the collaborators were delighted in each section.

3.8 Consider the degree of emotion

For the next step, we re-consider the calculation method to know the degree of the emotion. During watching the video that was divided into sections of the scenes, we try to grasp the changing of the biological information accordingly as following procedure (note that currently we only consider "joy" as the emotion):

(1) When the section is changed, we calculate the average pNN50 and the degree of awakening at the time determined that the joy of emotion.
(2) Determining the scale of their vector [21]. We consider that the magnitude of the vector is the “degree of joy”.
(3) Repeat from (1) to (2) until obtained the “degree of joy” in all sections.

If we use the value of the "degree of joy" for each section, individual differences in the biological information (e.g., heartbeat) appears. To correct it, we processed the "degree of joy" by performing the following calculation:

$$\text{degree of joy} = \left(\frac{\text{degree of joy}}{\begin{array}{c}\text{degree of joy The maximum of} \\ \text{the "degree } of\ joy\text{" in all sections}\end{array}} \right) \times 100$$

4. Second Experiment

4.1 Improved from the previous experiment

In this experiment, we solved several problems described in the preceeding section. The points are summarized as follows:

1) Evaluate the degree of an emotion

We changed the calculation method for recognizing the changing of emotion within the short time. First, we divided the time into shorter periods. In this case, we divide the sections for the video that arouse some emotion. Secondly, we consider a parameter of degree of maximum emotion that can understand the rate of the emotion. The questionnaire for the collaborator was prepared for them about the subjective judgment of emotion of each section. The answers for the sections was set as the maximum number on the formula. As a result, the formula calculated the result as the degree of an emotion. It would be easier to grasp the characteristic of the emotion for each section relatively. Note that in this experiment, the questionnaire is for self-evaluation of the degree of the joy of the section in the six stages. Additionally, we made some of the questions (in the three stages) about the collaborator and the attributes in the questionnaire. (Reference to [22]) By evaluating it after the experiment one can consider the difference between the attributes.

2) Improvement of pNN50, pulse sensor and the experimental environment

Instead of using the non-sensitive sensor, we used the new pulse sensor called "IWS920" "heart probe fingertip clip type IWPB2-FT"[23]. The pulse sensor is more precise and easier to use. Additionally, the number of pNN50 was increased from 10 to 30. Also, the robot was removed from the experiment because the collaborators noted that, with the movement, they cannot concentrate on the video.

4.2 Procedure, evaluation method

1. Experimental procedure

In this experiment, we set the procedure as follows.

(1) The collaborator answers the questions about their attributes from the questionnaire.
(2) The collaborator takes 2 minutes’ rest.
(3) The collaborator watches the videos (4 minutes). During this time, the sensors detect the biological information recalled, and make decisions it.
(4) The collaborator answers the evaluation questionnaire for each section of the video, then the questionnaire is evaluated.

The system obtains answers to the remaining two attributes in the questionnaire.
*(3) is carried out every second during the video viewing.

The number of the collaborators were 20 in total; 17 men (21 to 23-year-olds) and 3 women (21 to 22-year-olds). The video reminiscent of "joy" shown to the collaborators was changed to a specific comedy video that the experimenter has selected. Additionally, the experiment location was changed to a quiet laboratory environment.