An Emotional Space Modeling for the Adaptive Emotional Model Design Based on Sugeno Fuzzy Inference

Il-Kyoung Kwon¹ and Sang-Yong Lee²

Dept. of computer Science & Engineering, Kongju National University¹
Div. of Computer Science & Engineering, Kongju National University²
psent95@kongju.ac.kr¹, sylee@kongju.ac.kr²

Abstract

To maximize the quality improvement and tangibility of emotion-based personalized services, a lot of efforts are put into researches on emotional expression languages, measurement of emotions, emotional transference and expression model, personalized emotional space model, emotion-based personalized services, and so forth. To maximize quality improvement and tangibility of emotion-based personalized services, research on emotional modeling for quantitative and structural expression of human emotions needs to precede the others. In addition, a high level of inference on human emotions as well as an emotional model with learning capabilities is necessary for personalized emotion modeling.

To this end, this study defines the 12 emotional expression languages, which are defined in Thayer’s Valence-Arousal emotion model, with the fuzzy membership function. For emotional transference and inference modeling based on valence and arousal input, Mamdani and Sugeno Fuzzy Inference Methods are applied and evaluated. In this manner, this study provides the basis for an adaptive emotional inference system based on the personalized emotional model and neuro-fuzzy system required for personalized services.

Keywords: Emotional Space Modeling, Fuzzy, Neuro-Fuzzy, Sugeno Fuzzy Inference, Thayers Emotional Space Model

1. Introduction

As information technology continues to advance, ICT is turning its focus onto maximizing convenience or tangibility of services. In particular, the research on emotion-oriented services in consideration of subjective tendencies of individuals is expanding. To this end, many studies are conducted on situational recognition and adaptive learning methods in reflection of the subjective tendencies of individuals. In addition, studies on human emotions cover various areas, from psychological aspects for the examination of human nature to emotional space modeling, to express such psychological facets in a quantitative and structural manner. In this regard, other related researches are done on emotional transference and inference modeling, adaptive emotional modeling with learning capabilities for emotional personalization, etc., for emotion-oriented and personalized services.

For instance, the study on adopting emotion-based services in such application areas as robot and game is being actively conducted. When it comes to the decision-making of robots, such emotions as anger, pain, and fear need to be recognized for robots’ judgment upon dangers [1]. In the area of games as well, such emotional expression languages as boredom, challenge, excitement, frustration, and fun need to be defined to reflect the physiological signals of humans that may be shown in playing games. If it is possible to develop such
expression models to express these consecutively, they can be expanded to the area of game planning and development [2].

Further, some studies touch emotional data acquisition and recognition models based on physiological signals such as facial expression recognition, acquisition and modeling of human emotions based on voices, and so forth.

This study adopts the two-dimensional emotional model suggested by Thayer for the emotional modeling of users. Additionally, the study uses the fuzzy logic to process linguistic variables to efficiently express human emotions used in emotional space. For a high level of inference of transferred emotions, the Fuzzy Inference System (FIS) is applied. In the case of the FIS system, Mamdani Inference Method, which is a direct inference method, and Sugeno Inference Method, a mixed inference method, are applied in the experiment and evaluation.

In particular, this paper suggests an emotional modeling method for the personalized modeling of transferred and inferred emotional data in Fuzzy Inference System with no learning capabilities, as well as the structure of ANFIS, an adaptive fuzzy inference system based on Sugeno Inference System. All these methods stated above will make possible personalized emotional space and inference modeling with adaptability to new environments and learning capability [3].

2. Related Studies

2.1. Fuzzy and Fuzzy Inference System

The fuzzy theory addresses fuzziness on the basis of subjectivity that cannot be clearly judged. It describes the “extent of belonging to” a certain set by means of a fuzzy set, not a crisp set. The function can be gained by corresponding the fuzzy set to the coordinate axis, and this function has fuzzy characteristics accordingly. When the value of the function is large, it indicates the large extent belonging to the target objective, and when it is small, the other way. This is called a membership function. The function belonging to Fuzzy Set A is represented by $\mu_A$, which is a value between 0 and 1 in general[4].

Fuzzy Set A in the total set called “X” is a set specialized by $\mu_A$, the function expressed as $\mu_A : X \rightarrow [0,1]$. The value of $\mu_A(x)$ of Fuzzy Set A is called the membership value or grade. This membership value indicates the extent that Element x belongs to Set A. For instance, when the membership function belonging to Fuzzy Set A is $\mu_A : X \rightarrow [0,1]$ and $\mu_A(x)$ is near 1, the extent that Element x belongs to Fuzzy Set A is large. When $\mu_A(x) = 1$, Element x completely belongs to Fuzzy Set A; when $\mu_A(x) = 0$, Element x does not completely belong to A (however, X is the total set, and x is an element).

Such fuzzy sets are divided to the continuous type and discrete type. For example, when there is a fuzzy set $A = \{(\mu_A(x), x) : x \in X\}$ for the total set X, the continuous type fuzzy set can be expressed as $A = \int_X (\mu_A(x)|x)$. In the case of a discrete type, it is expressed as $A = \sum_{i=1}^{n} (\mu_A(x_i)|x_i)$. Among such fuzzy sets (membership function), the most common ones include triangle type, trapezoid type, and Gaussian type. This study adopts Gaussian type membership functions to define valence and arousal values; that is, the input for emotional expression languages.

Types of Fuzzy Inference Methods include direct inference method, indirect inference method, mixed inference method, and simplified inference method. The direct inference method is also called Mamdani Inference Method. As shown below, the variable at the latter part is a fuzzy number.

When the variable at the former part increases in the case of the direct inference method, the number of rules continues to increase. As a result, the working time increases and it
becomes difficult to determine the causality between the variables at the former and latter parts. Hence, this study applies the Sugeno Inference Method to process the latter part variable with real numbers. The Sugeno Inference Method is quite similar to the Mamdani Inference Method except the mathematical function used for the variable at the latter part. With regard to the Sugeno Fuzzy Model in the order of 0, it is possible to process the latter part variable with a singleton, which is of a real number. In fact, the Mamdani Inference Method is used mainly to obtain expertise, and the Sugeno Inference Method is advantageous for optimization since it contributes to efficient calculation. In addition, it works well with the adaptive neuro fuzzy system.

This system adopts both the Mamdani and Sugeno Inference Models to model emotional space. It also contains a comparative analysis on them.

2.2 Thayer Emotional Space Model

Thayer’s Emotional Model is also called a two-dimensional V-A (valence-arousal) emotional model. Arousal represents the transference from excitement to calmness as the value of strength fluctuates between exciting and calm. Valence indicates the emotional elements of positive and negative. As the value increases, it indicates positive emotion; as it decreases, it indicates negative emotion. The number of emotions that can be represented in the manner above is 12, and it is possible to express the intensity of each emotion as the V-A value fluctuates. To process the fuzziness of the emotional border and linguistic variables of the emotional expressions used in the V-A emotional model, an emotional space modeling is conducted on the basis of the fuzzy logic (Figure 1)[5].

![Figure 1. Four Quarterly Thayer Emotional Model](image-url)
3. FIS-based Emotional Space Establishment and Inference

3.1. Emotional Space Modeling Steps and Methods

To model the emotional space by means of the Fuzzy Inference System and to implement the emotional transference and inference modeling, 6 steps are taken based on the Thayer Emotional Model (Figure 2).

Since this study adopts the Thayer Emotional Model, a Fuzzy Inference System (FIS) design is required to establish an emotional transference and inference model based on the fuzzy logic. The Fuzzy Inference System requires rules for input, output, and inference. Depending on the inference method, the system elements may need to be modified accordingly. In this study, the inference system for Mamdani and Sugeno methods will be established and evaluated, and thus the rules and output to be used also need to be designed and adjusted.

Once the system structure for the basic input/output relation is decided, the input necessary for emotional determination and transference also need to be defined. Since the emotions of Thayer’s emotional model are decided based on valence and arousal values, a set of input for each value needs to be established. In particular, the size of emotions is quite vague that the basis for the fuzzy logic must be defined. To this end, the input variables are defined in a way that the extent of membership of valence and arousal values is calculated by means of the Gaussian type membership function.

In Thayer’s Emotional Model, the output corresponding to the input of valence and arousal values immediately lead to the decision of emotions. The number of emotions defined in the emotional model is 12 as shown in Figure 1. It is necessary to design the way to process output variables. The two types—Mamdani and Sugeno—are used in this study as emotional inference methods, and the ways to define output applicable to each method are different from each other.

Once the input/output values are defined, rules need to be made for appropriate emotional inference. In particular, the number of inference methods adopted in this study tends to...
geometrically increase depending on the number of inputs and outputs, and thus special attention is required. In this study, 49 rules in total are used.

Once the inference system is completed, the evaluation and adjustment should follow. The 7 following steps are to be taken to adjust the fuzzy system[6-11]:

<table>
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**Figure 3. Evaluation and Adjustment of the Fuzzy Inference System**

### 3.2. Design of the Fuzzy Inference System Based on the Emotional Model

Thayer’s emotional model is also called a V-A emotional model. In a V-A emotional model, emotion is defined with 12 types of linguistic expressions such as “Happy,” and the borders between adjacent emotions are vague (Figure 4). Figure 4 shows the emotional transference and inference model by means of the fuzzy inference system with the input/output characteristics of the V-A emotional model taken into consideration.

The types of input and V-A values, are defined with 7 fuzzy membership functions, and the values are between 1 and -1. The membership function was defined so that the 12 emotions could be sub-categorized into three different intensities (light, medium, and strong). The general inference system consists of two types of input: 12 types of output and 49 inference rules.
3.3. Definition of the Input/Output Fuzzy Set

Valence and Arousal values that were used as input of the inference system were defined with 7 types of Gaussian membership functions. Valence values were of a real number between -1 and 1, and they had positive or negative tendencies depending on the extent. Arousal values as well were of a real number between -1 and 1, and they had tendencies between exciting and calm depending on the extent (Figures 5 and 6).

The numerical expression to define the Gaussian type is as follows (the value is decided based on the value on the x-axis and the two parameters $\sigma$ and $c$):

$$f(x, \sigma, c) = e^{-\frac{(x-c)^2}{2\sigma^2}}$$

To express the membership function for valence input, $[\sigma, c]$ values can be arranged in order as follows: [0.202 -1], [0.15 -0.5], [0.08 -0.2], [0.08 1.5e-17], [0.08 0.2], [0.15 0.5], and [0.202 1] (Figure 5). Figure 6 shows the membership function for the arousal input, and the values of $\sigma$ and $c$ were same with those of valence.
The output of the inference system applying the Mamdani Inference Method was defined with the three Gaussian membership functions for the 12 emotional expression languages. In particular, the major membership functions for “Happy” are presented in Figure 7 below. They indicate the extent of emotions—strong, medium, and light. To express the membership functions for the output of each emotion, \([\sigma, c]\) values are arranged in order as follows: \([0.202\ 1.5e-17]\), \([0.202\ 1.5e-17]\), and \([0.202\ 1]\) (Figure 7).
The output of the Sugeno Inference Method was of a real number unlike that of the Mamdani Inference Method. The values are as follows depending on the extent of each emotion: light=0.15, medium=0.5, strong=0.85.

3.4. Definition of Inference Rules and Inference Methods

The general fuzzy inference system consists of two types of input: 12 output types, and 49 inference rules. The types of rules used are as follows:

\[ IF \ x \ is \ A \ and \ y \ is \ B, \ THEN \ z \ is \ C \]

Where, A, B, and C are the fuzzy number, x and y the antecedent variables, and z the consequent variable.

The following examples are some rules used in this study. The former part variables correspond to the V-A value and the latter part variable the fuzzy membership function for the 12 emotional values.

\[ IF \ \text{valence is positive-high and arousal is exciting-high} \ THEN \ \text{happy is happy-strong} \]
\[ IF \ \text{valence is negative-medium and arousal is calm-medium} \ THEN \ \text{bored is bored-medium} \]

Once the input variables, output variables, and inference rules are defined, it is necessary to define the inference methods. The Mamdani Inference Method follows the four steps below:

Step 1: To determine the suitability of the former part of each rule in reference to a given input
Step 2: To determine the inference results of each rule based on the suitability from Step 1
Step 3: To determine the final inference result based on the inference results of each rule
Step 4: To make it usable in actual fields through non-fuzzification

The following are the steps of the inference method by means of the Mamdani Inference Method when rules \( R_1 \) and \( R_2 \) are given:

\[ R_1 : IF \ x \ is \ A_1 \ and \ y \ is \ B_1, \ THEN \ z \ is \ C_1 \]
\[ R_2 : IF \ x \ is \ A_2 \ and \ y \ is \ B_2, \ THEN \ z \ is \ C_2 \]

Here, x and y correspond to the former part input, z the latter part output variable, and \( A_1, B_1, \) and \( C_1 \) is the fuzzy sets.

In Step 1, the suitability of each rule for the final values \((x_0, y_0)\) is determined by means of the following expression: (the smaller value \( [\min] \) of the suitability to \( A_i \) and \( B_i \) is taken)

For \( R_1 \):

\[ \text{Suitability of } R_1: W_1 = \mu_{A_1}(x_0) \land \mu_{B_1}(y_0) \]

For \( R_2 \):

\[ \text{Suitability of } R_2: W_2 = \mu_{A_2}(x_0) \land \mu_{B_2}(y_0) \]
Step 2 shows that the suitability from Step 1 is reflected in the latter part fuzzy set and the inference result of each rule is determined. However, the smaller value (minimum) of that from Step 1 and suitability to $C_i$ is taken.

Inference result of $R_1$: $\mu_{c'_{1}} = W_1 \wedge \mu_{c_1}(z), \forall z \in Z$

Inference result of $R_2$: $\mu_{c'_{2}} = W_2 \wedge \mu_{c_2}(z), \forall z \in Z$

Step 3 shows the final inference result: (the largest [maximum] of the suitability values of rules)

$$\mu_c(z) = \mu_{c'_{1}}(z) \lor \mu_{c'_{2}}(z)$$

Step 4 is a step of fuzzification. The inference result in Step 3 is a fuzzy set. When the final value of the inference result is necessary, this fuzzy set is to be defuzzified. In this study, the “center of gravity” method is applied and the expression is as follows:

$$z_0 = \frac{\int \mu_c(z) \cdot z \, dz}{\int \mu_c(z) \, dz}$$

As for the Sugeno Inference, the latter part variable is lineal and thus it is a type of lineal inference. In this study, however, the real numbers were used to apply the simplified inference method. For example, the simplified inference method when there are two input variables and 1 (lower case of L) input variable is as follows:

$$R_i: IF \; x \; is \; A_i \; and \; y \; is \; B_i, \; THEN \; z_i \; is \; C_i, \; i = 1, 2, \ldots, l$$

Where, $i$ : rule No. $l$ : number of rule(s), $A_i$, $B_i$ : fuzzy set, $C_i$ : real number value

When the suitability of the former part of rule $i$ is $w_i = \mu_{A_i}(x) \wedge \mu_{B_i}(x)$, the final inference result of rules - $z_i^*$- is as follows:

$$z^* = \frac{\sum_{i=1}^{l} w_i C_i}{\sum_{i=1}^{l} w_i}$$

4. Experiment and Evaluation

In this study, Mamdani and Sugeno methods were adopted as the inference methods for the fuzzy inference system. It also includes the experiment and evaluation. The most significant difference between the two methods is how to process the variables at the latter part. The fuzzy set type corresponds to the Mamdani method, and the real number type the Sugeno method. Further, the configuration and number of rules are the same, but performance factors such as inference rates and modeling results are significantly different.
Figure 8. V-A Emotional Space Modeling Results for Each Inference Method (1st Quarter)

Figure 9. Neuro-fuzzy Equivalent System for Personalized Emotional Modeling
As shown in Figure 8, the two models show the emotional space modeling results based on the fuzzy inference system for three emotions—pleased, happy, excited—which correspond to the 1st quarter of the V-A emotional model. In the case of the Mamdani Inference Model to the left, the output variables strong, medium, and light were processed with the Gaussian type membership function. As a result, the values were expressed in reflection of the shapes of the membership function but the overlapped area drastically increased as the size of emotions exceeded 0.5 depending on the V-A values. This indicates that it is difficult to specifically discern the fuzzy characteristics of the three emotions corresponding to the 1st quarter.

When the size of emotions is below 0.5, the three emotions are modeled in almost the same space. To solve this problem, therefore, the shape, scope, and number of the membership function need to be adjusted according to the system evaluation and adjustment procedures to process the output variables appropriately. When the number of membership functions increases, however, it is necessary to make new rules, which will increase the burden of operations.

The modeling result by means of the Sugeno method to the right looks more stable than the Mamdani method and the operation rates are also higher. In particular, the space for each emotion defined in the V-A emotional model is quite distinctive from each other. The overlapped area of emotions is also quite properly distributed. Since the values of output variables are of a real number, this is advantageous in that the correction of modeling results is faster than that of the Mamdani method which should adjust all of the shapes, value ranges, etc. of the membership function. Additionally, learning about the membership function is required for the adaptive emotional space modeling necessary for personalized services. To this end, the Sugeno type of inference method can be applied to establish the Adaptive Neuro Fuzzy Inference System (ANFIS). Figure 9 below shows the system diagram to establish the neuro-fuzzy system based on the fuzzy inference system.

This study verifies that it is possible to establish an emotional transference and inference model based on the fuzzy inference system that utilizes the V-A emotional model. In addition, the modeling result of the Sugeno method is superior to that of the Mamdani method when it comes to the inference method. Thus, it is possible to establish an adaptive emotional inference system for personalized services.

5. Conclusion

This study aims to suggest a method to model emotional space for emotion-based personalized services required for the quality enhancement of personalized services. In particular, emotional space modeling requires appropriate transference and inference according to the induced emotions. To this end, the study has verified that it is possible to establish the emotional transference and inference system based on the V-A emotional model by means of the fuzzy inference system. It turned out that the Sugeno method used in the inference process was better in the spatial expression of the V-A emotional model and faster than the Mamdani method. Further, the maintenance was relatively easy. It is expected that this study will be a basis for adaptive emotional space modeling for ANFIS-based adaptive personalized services in the future.

Acknowledgements

This work was supported by the research grant of the Kongju National University in 2013.
References


Authors

Il-Kyoung Kwon, received the B.S., M.S. degrees in computer science from Kongju National University, Gongju, Korea in 1999, 2001, respectively. His research interests include intelligence systems, emotion modeling and context awareness based personalization services.

Sang-Yong Lee, received the M.S. degree in system science from Tokyo Institute of Technology, Tokyo, Japan in 1988 and the Ph.D. degree in computer engineering from Chung-Ang University, Seoul, Korea in 1993. From 1988 to 1989 he had been a researcher at NEC, Tokyo, Japan. Also he had been a visiting professor at University of Central Florida, Orlando, USA from 1996 to 1997. Since 1993 he has been a professor of the division of computer science and engineering, Kongju National University, Gongju, Korea. His research interests include intelligent systems, context awareness and ubiquitous computing.