Fuzzy Perception, Emotion and Expression for Interactive Robots*

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Abstract - *Future robots need a transparent interface that regular people can interpret, such as an emotional human-like face. Moreover, such robots must exhibit behaviors that are perceived believable and life-like. In this work we will propose the use of fuzzy logic for effectively constructing the whole behavior system of these robots. This will not only simplify the design task, but also enrich human-robot interaction. The latter claim is justified by effortlessly generating intermediate and blend of emotions from a few basic emotions. Additionally, fuzzy motor commands yield smooth life-like motions and therefore improve believability.*

Keywords: Human-robot interaction, artificial emotions, facial expressions, fuzzy rules, perceived intelligence.

1 Introduction

Most robots today can interact only with a small group of specially trained individuals due to their unconventional communication mechanisms. If we are ever to achieve the use of robots as helpmates in common, everyday activities, this restricted audience must expand. We will need robots that people who are not programmers can communicate with. Much work is being done on the side of receiving input from humans (gesture and speech recognition, etc.), but relatively little has been done on how a robot should present information and give feedback to its user [4].

Robots need a transparent interface that regular people can interpret. A human-like face has been shown to be a successful candidate as a natural interface. Previous work on software agents suggests that people find interaction with a human-like face more appealing than an agent with no face [20, 29]. [21] even shows that people are more willing to cooperate with agents that have human faces.

In addition, for embodied creatures that interact with humans, emotions are an essential part for providing the illusion of life [20, 23]. This is typically based on the claim that such agents can interact better, in a more natural way with humans and look more realistic and believable [16]. The expression of emotion in the face is an important biological aspect of emotion that has significant implications for how emotion is communicated in social situations [7]. Emotional agents are particularly appropriate for educational and entertainment domain [8, 20, 26].

Although most of recent works on emotional creatures has been focused on synthetic and virtual agents displayed on computer screen, it has been shown that physical robots seem more believable. For instance, people expect that moving objects require intelligent control, while flat images likely result from the playback of a stored sequence as in film or television [18]. In addition, a physical robot can be viewed from different angles, it can be touched and its approach toward people may cause fear in them. Apparently, an animation does not have strong impacts on people.

In this paper, we will propose the use of fuzzy logic for effectively constructing the whole behavior system of a physically implemented robot face. Fuzzy approach will not only simplify the design task, but also enrich the interaction between human and robot. The latter claim is justified by effortlessly generating intermediate and blend of emotions from a few basic emotions. Additionally, fuzzy motor commands yield smooth life-like motions and therefore improves believability. This paper is organized

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as follows: In section 2 we will review the related works on emotional interactive robots. Section 3 explains motivations for using a fully fuzzy system and in section 4 we will show a simple fuzzy rule-base for generating life-like behaviors. Section 5 offers some implementation details and experimental results. Then in 6 we will conclude and suggest some possible future works.

2 Related Works

The use of emotions and their facial expressions in the context of human–robot interaction is in infancy. However, it is receiving increasing attention. Here we give an overview of some works in this field.

Sparky is a robot developed by Scheeff and colleagues with the aim of exploring ideas in human-computer interface and interactive robotics [27]. It uses facial expression, gesture, motion, and sound. The robot's only task is emotional expression in the context of social interaction. Unlike the other robots presented here, Sparky is not autonomous but teleoperated.

The Affective Tigger [19] is an expressive toy developed by Kirsch as a tool for the social and emotional awareness education of small children. Facial and vocal expressions reflect the emotional state of the toy as a response to the child's physical manipulation. Each sensor produces an emotional trigger either in the positive or negative direction.

eMuu is a robot developed by Bartneck to function as the interface between the user and intelligent home. The user can instruct the robot to perform a number of tasks of home [2]. The emotion engine, which controls the emotional state and the facial expression, is based on the OCC model [24].

Feelix, a robot built by Canamero [5] is constructed from LEGO Mindstorms™. Feelix has been used as a research platform for human robotic interactions study. It uses a combination of two different emotion representations, discrete basic emotions and continuous dimensions. Feelix only perceives tactile stimuli, which gives little information about environment.

Minerva [30], which was developed by Thrun, is an interactive tour-guide robot. Using a state machine, a transition toward happy state is made when the robot can freely move and a transition toward sad state is made when people block its way. The emotional state of the robot is directly mapped to facial expressions. Minerva uses reinforcement learning to attract people by issuing a series of actions and then evaluating them by closeness and density of people around it. Minerva cannot represent different degrees of emotion intensity a blend of them.

In comparison with robots that were reviewed so far, Kismet, developed by Breazeal [3] as a test bed for learning social interactions, has a very sophisticated brain. Based on Synthetic Nervous System (SNS) mechanism. Kismet displays a wide variety of emotional expressions that can be mapped onto a space with dimensions arousal, valence, and stance.

3 Motivations

In the simplest case, an interactive robot should consist of three basic modules for handling sensory data, motor commands and emotional states. In this section we will give some reasons that why implementing each of these modules using a fuzzy approach is beneficial. For the sake of simplicity we discuss sensory motor and internal states separately.

3.1 Internal Representation

Various methods have been proposed for modeling emotions. For instance, Damasio suggests somatic-marker mechanism for modeling emotions [6]. TABASCO architecture [28] is a model based on the emotion appraisal theory. OCC theory of emotions is another popular model [24].

A problem with these models is their black and white nature. El-Nasr [11] addresses some constraints imposed by this restriction. She summarizes such models as assessment of a perceived event as being severely desirable or undesirable. So the idea of partial achievement of goals and the idea of an event satisfying multiple goals or satisfying some goals and not the others were not considered. She also mentions the problem of abrupt changes in behaviors when emotions are mapped to behaviors by techniques such as interval mapping. Based on a subjective evaluation, she has shown improvements achieved using a fuzzy emotional model.

Furthermore, most of these models focus on modeling emotional system as it seems to be in humans and animals. Using them is helpful when improving our knowledge about the nature of emotion is considered. However, the best application domains of interactive robots are toys, educational tools, entertainment tools, and therapeutic aids [8, 15, 20, 26]. In these applications the major concern is not to simulate naturally occurring processes using hypothesized underlying mechanisms, but obtaining high degree of believability and a natural interface for human-robot interaction [16].

Therefore, rather than looking for an accurate model of emotion process, we suggest modeling it from a behaviorist viewpoint. Use of fuzzy logic for modeling emotional behaviors has a number of advantages:

- It is straightforward to implement software for a fuzzy system.

- It provides a convenient means for triggering multiple emotions.

- Changes occur smoothly, resulting in natural and life-like behaviors.

- Since a fuzzy system is based on linguistic variables, its design and understanding is convenient.

- It focuses on achieving the desired behavior, which is the main concern in human-robot interaction, unlike other emotional models that focus on accurate internal modeling.

- Fuzzy is a model free approach. Thus, there is no limitation imposed by model like other approaches. Designer can easily add or remove rules and watch their effect until achieving the desired behavior.

3.2 Perception and Action

Applying fuzzy logic to modeling emotional agents is not a new idea. As we mentioned in 3.1, El-Nasr has proposed a fuzzy architecture for modeling emotional process [12]. She has applied her model to synthetic characters within an animation world. However, her focus is on internal representation of emotion and considers events and actions as black and white entities [11]. However, we argue that in reality both perception and action are a matter of degree.

It is not hard to conclude that the reflected emotion intensities on facial expressions carry important information, which can influence the dynamic of interaction. For instance, it has probably happened to you that when the one whom you are speaking with smiles, you tend to smile too. If she starts cachinnating, your smile becomes stronger and may even make you laugh loud. This indicates that her emotion intensity influences yours and vice versa. Due to the role of emotion intensity in our interactions, its expression by interactive robots can enrich their communicative ability too. Additionally, it improves degree of believability.

Nevertheless, some robot faces reviewed in section 2 are neither able to exhibit intensity of emotions nor blending emotions [2, 5, 19, 30]. In fact, the reflected emotion on their faces is chosen from a few discrete expressions. Some other researchers have incorporated intensity expression into the motor capabilities of their robot faces. However, their approaches rely on ad-hoc interpolation requiring several coefficients [3] or post processing such as filtering to obtain a smooth result [27]. These goals can be achieved automatically and more effectively within a fuzzy framework, i.e. achieving natural motions using readable rules. Unlike ad-hoc coefficients, fuzzy rules are generally based on linguistic variables. So due to their clear meanings, fine-tuning their parameters is straightforward.

So far we only talked about fuzzy actions. We claim that perception and events are a matter of degree too. In fact, different degrees of an event can result in different intensities of an emotion, or even trigger different emotions. For instance, consider an event like moving a ball in front of a robot. The degree of nearness can influence the triggered emotion.

If nearness is low, the ball may not seem important enough to capture robot's attention and thus it will have no effect on robot's emotional state. If the ball is brought near, this may seem interesting to the robot and make it happy. However, bringing the ball too near can scare the robot. Fuzzy logic is an excellent tool for capturing this degree of membership in a structured form.

4 Fuzzy Approach

Generally, there are two different emotion representation methods, discrete basic emotions and continuous dimensions. Basic emotions are those that can be taken as building blocks out of which other, more complex emotions form. A particular case of basic emotions is the one proposed by Ekman [9]: anger, disgust, fear, happiness, sadness and surprise.

In continuous space representation, the two most commonly used dimensions are valence (positive/negative) and activation or arousal (calm/excited) [31]. It has been shown that these two dimensions are not enough to distinguish among all the basic emotions. For example fear and anger are both characterized by negative valence and high arousal. Therefore sometimes another dimension, potency (powerfulness/powerlessness), is added [5].

We preferred basic emotion representation, because it is easier to be interpreted by human and therefore more suitable for constructing a fuzzy rule-base. In addition, these emotions correspond to distinct facial expressions, which are supposed to be universally recognizable across cultures [9, 10, 17]. Intermediate emotions or blend of emotions are automatically obtained by fuzzy operations. In fact, the overlap that usually exists between fuzzy sets causes more than one rule to apply at any moment. This provides fuzzy systems with the ability to generalize between rules. As a result, since changes in events typically arise slowly, smooth transitions on the emotion surface occur between rules

When emotions are computed according to the perceived events, they are mapped to facial expressions. Depending on the amount of overlap between fuzzy sets, a mixture of emotions is obtained. Some researchers prefer to filter the emotion mixture to get an emotional state [11, 12]. We however did not favor it so that transitions among emotional states occur smoothly and resemble a natural motion in face.

In fact, achieving a life-like motion in interactive robots is itself a challenging topic [27]. Since we eliminated such a filter, care must be taken about consistency in rule base. This prevents from conflicting rules, e.g. taking robot to highly happy and highly scared emotional states on the same event.

Many emotional response patterns are hard-wired in the brain's circuitry and they are not learned [14]. Consequently, elimination of learning from emotion-action mapping does not degrade performance and believability of the robot. However, the particular stimulus conditions that activate emotions are mostly learned by association through Pavlovian conditioning. For the sake of simplicity, currently our system maps events to emotions innately too, but learning can be added to adapt emotion-action rules (e.g. conditioning [1, 25]) and improve believability.

In this article, our aim is to demonstrate the plausibility of developing a fully fuzzy system for generating emotional behaviors in interactive robots. In order to make a start, we implemented a reactive system (i.e. events directly affect emotional states and accordingly motor commands). Ultimately, there can be feedback loops or memories in the system. Obviously, our simple implemented platform is a suitable substrate for adding deliberative tasks such as planning, non-verbal dialogues, fuzzy reasoning and decision-making.

Stimuli and motor commands are usually physical signals, so they must be fuzzified and defuzzified respectively. Since our implemented system is reactive, characteristics of event-emotion rules such as shape and parameters are the only factors for shaping personality of the robot. For instance having fear emotion be activated more strongly with objects that are in a short distance, yields a timid personality.

5 Experimental Results

We used our robot face Aryan [22] to implement and evaluate the proposed idea. Aryan utilizes eight degrees of freedom to move its neck and facial features. Briefly, movements are pan/tilt for neck, joint tilt for eyes, independent pan for each eye, elevation for eyebrows, eyebrows arcing and finally opening jaw. Three cameras, placed on its face, make up an active vision system capable of detecting and tracking human faces or hands in near real-time. The robot has been built from scratch at home with off-the-shelf components. Its software is written in c language and executed on a Pentium 200 MHz with Linux OS installed on it. More details about Aryan can be found in [22].

Table.1 Perception to Emotion Rules

Velocity / Distance	**Stationary**	**Slow**	**Fast**
Very Near	VA,NS,NF	A,NS,F	NA,NS,VF
Near	A,NS,NF	NA,NS,NF	NA,S,F
Far	VA,NS,NF	A,S,NF	NA,VS,NF

Since Aryan has rigid lips, it cannot represent all basic emotions. Therefore, we had to choose a subset of basic emotions: surprise, anger and fear. Appropriate motor commands generate facial expressions according to intensities of emotions. An event is represented by a fuzzy 2-vector with fuzzy components, distance and approaching velocity (of a person relative to robot). These components are estimated by Aryan's vision system. When Aryan is alone or a person blocks it, it gets angry. A slow approach toward Aryan surprises it. A sudden approach however scares the robot.

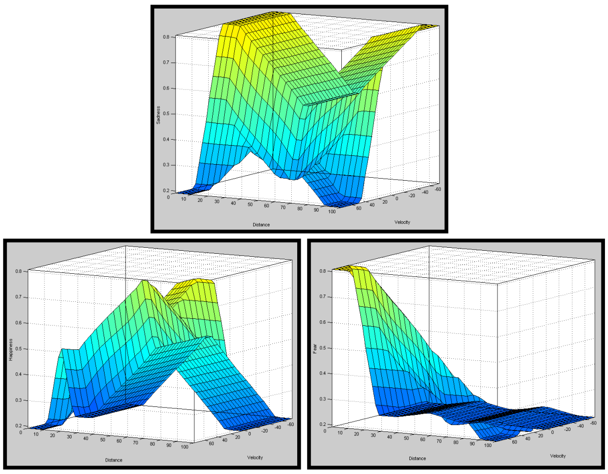

Figure 1. Emotion Surface
(Top: Anger, Left: Surprise, Right: Fear)

We implemented two groups of rules, one for mapping events to emotions and another for mapping emotions to facial expressions. Distance is defined to be very near, near or far. Velocity belongs to sets stationary, slow or fast. Emotion intensities are also represented by three fuzzy sets. For instance, there are three sets for anger namely not angry (NA), angry (A) and very angry (VA). These linguistic variables are simulated by triangular membership functions with 25 percent overlapping between adjacent fuzzy sets, according to Kosko's rule of thumb. Table.1 summarize the applied rules for events to emotions mappings of anger, fear and surprise.

For the first mapping, event to emotion, we used Mamdani's model with centroid defuzzification to get emotion intensities. The result is then used by expression process. Mamdani's model uses sup-min to get the matching degrees for the rules. Emotion surface of three implemented emotions, anger, fear and surprise versus distance and velocity are shown in Figure 1.

After firing the rules and getting a mixture of emotions, they are mapped to facial features by another set of fuzzy rules. Due to the lack of space and larger number of rules for this mapping, we cannot list them. They simply relate emotion vectors with fuzzy components, each of which representing one of emotions to the state of each degree of freedom in the face.

The mapping is such that it resembles appropriate expressions. The states for jaw and eyebrows elevation are represented by four fuzzy sets and the states of eyebrows arc by five fuzzy sets. For instance, jaw can be very open, open, less open and closed. We also considered a neutral expression activated when none of the emotions fire strongly, i.e. (NA,NS,NF). Figure 2 shows Aryan in action, detecting a hand and tracking it. The intensity of surprise increases as the person approaches his hand toward the robot.

6 Conclusion and Future works

We argued that the perceived emotion does not necessarily require an accurate replication of human or animal emotional system. Therefore, in applications such as human-robot interaction, where the main concern is having a natural and affective communication, we can bypass computational models of emotion, yet achieve a believable emotional behavior.

We showed that how these behaviors could be constructed by a fully fuzzy architecture, from perception to action, that not only seems more realistic but also easier to implement. Using a compact and structured set of fuzzy rules, we could obtain intermediate or blend of emotions from a set of discrete basic emotions and also achieve life-like motion effortlessly.

The system discussed here was a simple prototype of an emotional system incorporating only innate emotion activation. One obvious direction for future work is to incorporate learning. Experience can change the way that our emotions are activated, e.g. by Pavlovian conditioning. When adding learning, care must be taken to avoid conflict in rules

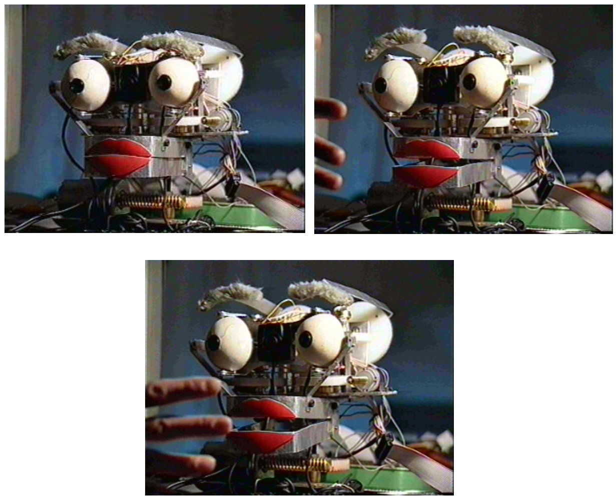

Figure 2. Aryan becoming surprised

Additionally, we are going to extend the reactive behaviors of our robot to more high-level tasks such as communication with non-verbal dialogue for regulating social interaction.

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