

Modeling the Body Movements and Feelings of Humanoid Robots Using Fuzzy Logic

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Abstract

Robots having a body shape similar to the human body and resembling the human behaviors are called humanoid robots (HRs). They are assumed to improve the quality of human life in the future by performing human tasks such as assisting the sick and elderly people and doing dirty or dangerous jobs. They should perfectly resemble humans' movements and feelings such as smiling, laughing, crying, getting surprised, getting sad, getting disgusted, or getting angry, if we really want to call them humanoid robots. Human feelings cannot be represented by 0-1 logic since an emotion can arise as different consequences of an infinite number of situations. Fuzzy logic is an infinite valued logic whose continuous values are between 0-1 and can be modeled by the fuzzy set theory introduced by Zadeh [1]. This paper provides ideas on how fuzzy set theory can be used to express human behavior and emotions in humanoid robots.

Keywords: Humanoid robot; Human feelings; Fuzzy logic; Fuzzy set theory; Intuitionistic fuzzy sets; Spherical fuzzy sets

Introduction

Humanoid robots imitate human feelings and human mechanisms of decision making and information processing. Several prototype humanoid robots for different purposes have been developed by various laboratories and universities. The first anthropomorphic intelligent robot WABOT (WAseda roBOT) was developed by Waseda University of Japan in 1973 (Figure 1). It had integrated systems for sensing, locomotion and manipulation inspired human capabilities. Later, Wabot-2 was developed in 1985 and it could play a piano. In 1986, Sony developed ASIMO, which was walking and climbing stairs. In 1993, MIT developed a humanoid robot having different but discrete facial expressions (sad, calm, surprised, etc.) and body components with different degree of freedoms.

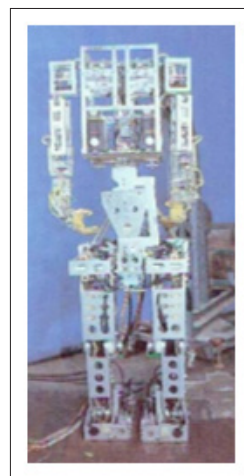


Figure 1: Wabot.

Figure 2 illustrates some more recently developed humanoid robots. Sophia has been developed by Hong Kong based company Hanson Robotics in 2016. Sophia has only 60 different facial expressions. Kodomoroid developed by Hiroshi Ishiguro Laboratories in 2014 is a teleoperated humanoid robot resembling a human child. Jia developed by a Chinese team



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at the University of Science and Technology of China in Hefei could move her arms, create different facial expressions, and answer to human conversations. Mirai Madoka was developed by a Japanese tech Orix car rental agency in 2016. Junko Chihira is a humanoid developed at Toshiba having the ability to make human-like facial expressions. The vagueness and impreciseness in humans' feelings and movements can be captured by the fuzzy set theory introduced

by Zadeh [1]. In this theory, everything is a matter of degree and cannot be well defined by discrete logic. In the ordinary fuzzy sets, an element is determined by only a membership degree whereas an element in the extensions of ordinary fuzzy sets is determined by a membership degree and a non-membership degree, in which their sum is not necessarily equal to 1. The new extensions of fuzzy sets try to consider the hesitancy in human thoughts.



Figure 2: Recently developed humanoid robots.

Using classical logic, you can only code feelings and movements that correspond to a certain number of events. However, people have completely different facial expressions and body movements in the face of countless different events. For example, a facial expression with tears of happiness and that with tears of losing a loved one are completely different. Besides, the tears of happiness when someone gets a marriage proposal and the tears of happiness of an athlete who finishes the marathon in the first place have completely different facial expressions. The answer to how these infinite numbers of cases can be modeled is of course the fuzzy set theory. The rest of the paper is organized as follows. Section

2 introduces the fuzzy set theory briefly. Section 3 presents the ideas on how fuzzy sets can be used in modeling the feelings and movements of humanoid robots. Section 4 includes the conclusions.

Fuzzy Set Theory

Fuzzy set theory found a wide application area in science and technology [2,3]. Decision making is one of the most attractive research areas with fuzzy sets [4,5]. Since ordinary fuzzy sets have been introduced by Zadeh [1], many extensions of them have appeared in the literature. Figure 3 illustrates the fuzzy set extensions with their historical order.

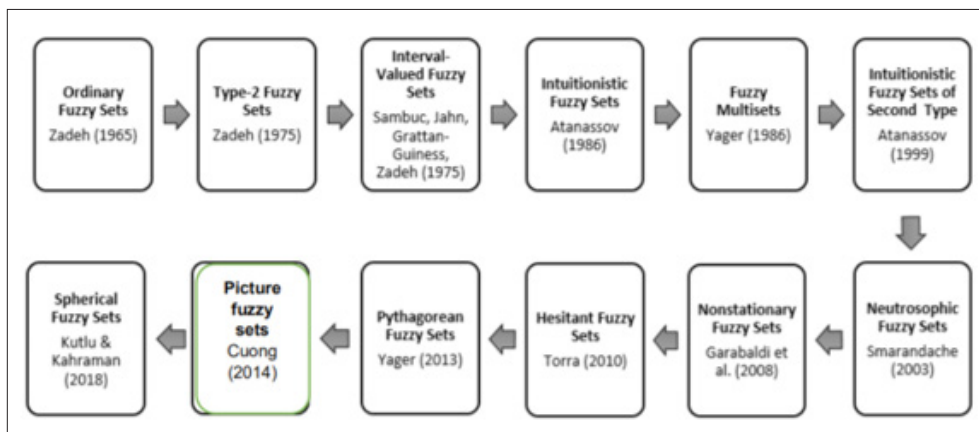


Figure 3: Fuzzy set extensions.

We can classify these recent extensions into two main groups:

- a) Intuitionistic fuzzy sets and its extensions including Pythagorean fuzzy sets, fermatean fuzzy sets, and q-rung orthopair fuzzy sets,
- b) Picture fuzzy sets and its extensions including spherical fuzzy sets and t-spherical fuzzy sets. First group extensions involve elements with one membership degree and one non-

membership degree whose powered sum of them is at most equal to 1 with a dependent hesitancy parameter.

Second group extensions involve elements with three independent elements which are membership degree, non-membership degree, and a hesitancy degree whose powered sum of them is at most equal to 1.

An ordinary fuzzy set \tilde{A} is represented by Equation (1):

$$A = \{(x, \mu_A(x)) \mid x \in X\} \quad (1)$$

where the function $\mu_A: X \rightarrow [0,1]$ defines the degree of membership.

An intuitionistic fuzzy set \tilde{I} in X is defined as in Equation (2):

$$\tilde{I} = \{(x, \mu_I(x), \nu_I(x)) \mid x \in X\} \quad (2)$$

where the functions $\mu_I: X \rightarrow [0,1]$ and $\nu_I: X \rightarrow [0,1]$ define the degree of membership and the degree of non-membership of an element to the set I , respectively, with the condition that.

$$0 \leq \mu_I(x) + \nu_I(x) \leq 1, \text{ for } \forall x \in X \quad (3)$$

The degree of hesitancy is calculated as follows:

$$\pi_I(x) = 1 - \mu_I(x) - \nu_I(x) \quad (4)$$

The second powers of the parameters in (3) and (4) yield Pythagorean fuzzy sets.

Fuzzy Sets & Humanoid Robots

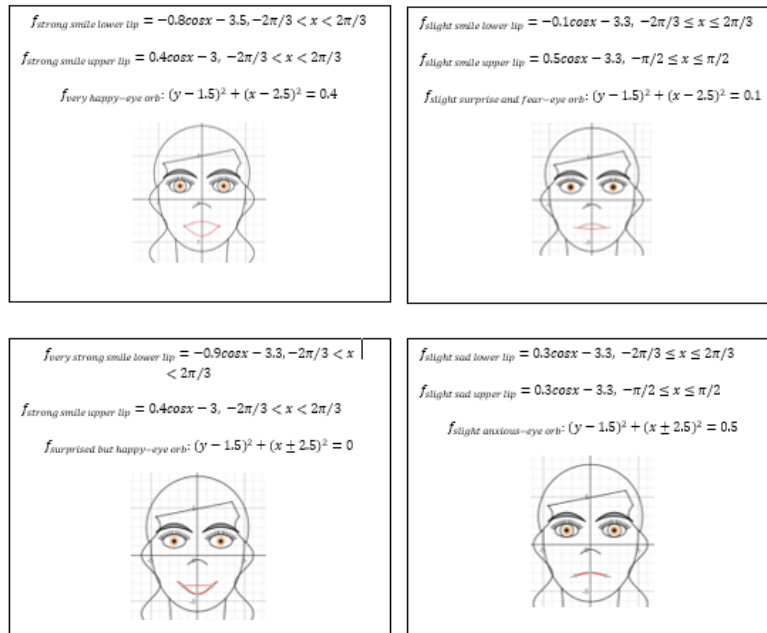


Figure 4: Smile and eye orb using mathematical functions.

The feelings and behaviors of a HR must be appropriate to the event it meets. Based on a discrete classification, humans have 21 different facial expressions. However, it is clear that this number is insufficient for representing infinite number of expressions of human feelings. Besides, the facial expressions are not universal and may change from a culture to another. Let's assign membership and non-membership degrees of happiness for some examples of different feelings when intuitionistic fuzzy sets are used [7]. Assume that humanoid robots hear that "Your friend had a traffic accident.", then the degree of feeling may be (0, 0.80). When it is "Your friend survived a traffic accident.", then the degree of feeling may be (0.50, 0.35) or as an interval, [(0.40, 0.60), [0.30, 0.40]]. When it is "Today

Picture fuzzy sets were introduced by Cuong [6]. A picture fuzzy set \tilde{A} on the universe X is defined as

$$\tilde{A} = \{(x; \mu_I(x), \eta_A(x), \vartheta_A(x)) \mid x \in X\} \quad (5)$$

where $\mu_I(x) \in [0,1]$ is called the degree of positive membership of \tilde{A} ; $\eta_A(x) \in [0,1]$ is called the degree of neutral membership of \tilde{A} and $\nu_A(x) \in [0,1]$ is called the degree of negative membership of \tilde{A} , satisfying the following condition.

$$0 \leq \mu\tilde{A}(X) + \eta\tilde{A}(X) + \nu\tilde{A}(X) \leq 1, \forall X \in X. \quad (6)$$

Then for $x \in X$, the degree of refusal membership of x in \tilde{A} is given as

$$\pi\tilde{A}(x) = 1 - \mu\tilde{A}(x) - \eta\tilde{A}(x) - \nu\tilde{A}(x) \quad (7)$$

The second powers of the parameters in (6) and (7) yield the spherical fuzzy sets.

is your friend's birthday.", then the degree of feeling may be (0.80, 0). When it is "Your friend died. ", then the degree of feeling may be (0, 0.90). When it is "Your friend died on his birthday.", then the degree of feeling may be (0, 0.95). When it is "Your friend's friend died.", then the degree of feeling may be (0, 0.75) [8]. Mathematical relations for some of the most common facial expressions can be in the form of simple mathematical functions which can model expressions such as smiling, frowning and eyebrow raising. Using classical functions, the face expressions are tried to model as illustrated in Figure 4; [9]. As it is seen in Figure 4, feelings can be modeled by mathematical functions and the coefficients and constant values can be changed between two values in order to

express the feelings from slight case to strong case such as slight anxious to strong anxious [10-13]. Linguistic terms can be best modeled by the extensions of fuzzy sets for this purpose. Let k be a coefficient as in Equations (8) and (9):

$$f_{smile\ lower\ lip} = -k \cos x - 3.3, -2\pi / 3 \leq x \leq 2\pi / 3 \quad (8)$$

$$f_{smile\ upper\ lip} = k \cos x - 3.3, -\pi / 2 \leq x \leq \pi / 2 \quad (9)$$

The coefficient k can be represented by an intuitionistic fuzzy number as in Figure 5.

The function in Figure 5 can be represented by the following α -cuts:

$$\mu_L = 0.20 + 0.15\alpha, \mu_R = 0.50 - 0.15\alpha$$

$$v_L = 0.35 - 0.25\alpha, v_R = 0.35 + 0.25\alpha$$

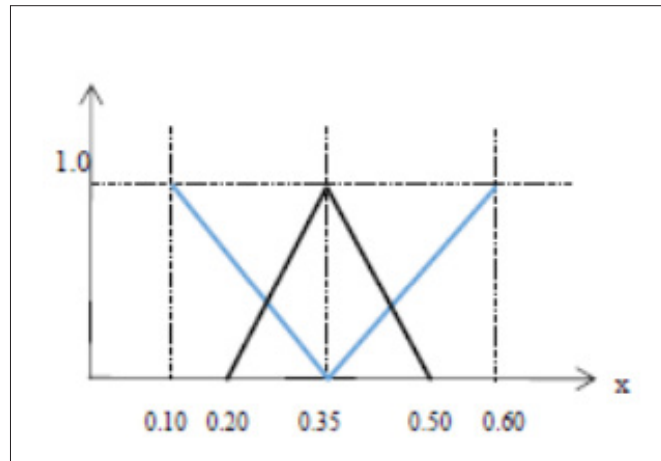


Figure 5: Intuitionistic fuzzy number for the coefficient k .

The fuzzy function between very slight smile and medium smile (v_{ss} & m_s) then becomes.

$$f_{v_{ss} \& m_s} = -([0.20 + 0.15\alpha, 0.50 - 0.15\alpha], [0.35 - 0.25\alpha, 0.35 + 0.25\alpha]) \cos x - 3.3, -2\pi / 3 \leq x \leq 2\pi / 3$$

Conclusion

Research on humanoid robots is one of the most attractive topics in engineering today with the aim of producing autonomous humanoid robots thinking and moving like human beings. Classical logic approaches are not sufficient to model a humanoid robot as a copy of human being [16,17]. Continuous logic approaches should be used to capture the infinite number of feelings of human beings. Fuzzy sets try to define a problem under vague and imprecise environment. New extensions of fuzzy sets provide a more detailed membership function with additional new parameters. These parameters can be successfully used in modeling the human-like behaviors of humanoid robots. Feelings and movements of humanoid robots can be directed by these membership functions much easier than classical control mechanisms [18,19].

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