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AI-enabled emotion-aware robot: The fusion of smart clothing, edge clouds and robotics

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ABSTRACT

Mental health has become a severe problem that significantly influences people's living quality. With the rapid development of science and technology, a completely new direction for mental health improving by using the interaction between robots and people has emerged. As an intelligent personal agent, a robot can be easily accepted in people's daily life, meeting users' behavior and mental demands to a certain extent. Nevertheless, the existing robot design is very limited, and a household personal robot is too large to be carried anywhere . The usage of wearable devices is simple, but these devices cannot offer diversified services. Therefore, this paper puts forward an emotion-aware system that integrates a personal robot, smart clothing, and cloud terminal. A new 'people-centered' emotion-interaction mode is realized. Namely, personal robot and smart clothing supplement each other seamlessly and interact jointly with users . Artificial intelligence technology and knowledge graph are used to design emotion perception and interaction algorithms including intelligent recommendation, relation recognition, emotional expression recognition. Also, different scenarios are analyzed . Finally, a testbed is built to carry out relevant tests to verify the effectiveness of the proposed algorithms and emotion-aware system. According to the obtained test results, the system can be widely used to serve people and improve people's mental health.

1. Introduction

Due to the accelerated pace of people's life and increasing competitive pressure, people's mental sub-health has become a global phenomenon. According to the statistics, in 2017, about 46,600 thousand American adults suffered from some kind of mental diseases, which accounted for 18.9% of all American adults [1]. Moreover, the data released by the World Health Organization showed that about 322 million people at different ages suffered depressive disorder, which accounted for more than 4% of the world population [2]. In the period 2005–2015, the number of patients with depressive disorder increased by 18%. Thus, the mental health problem has become a severe global problem [2]. The major breakthrough in the fields of social networking, Internet of Things, sensor networks, etc. has facilitated the exchange and integration of humans' social space, network space, and realistic physical world. Moreover, robot technology can be used to design a new "people-centered" emotion-interaction mode that widely serves people and improves users' mental health.

Up to now, some intelligent robots have been designed to realize the interaction between humans and machines. Namely, robots have been used in early education, diagnosis, and treatment of the children's infantile autism and the service for mental health [3–5]. Therefore, intelligent robots can be greatly helpful for improving both people's living quality and their mental health. On the one hand, the one-to-one interaction between an intelligent robot and a user involves private emotion interference and guides the user to relieve feelings properly. On the other hand, the tacit understanding formed by a long-term interaction with a user helps the robot to know the mental state of the user sufficiently, which can meet user's behavior and mental demands. In the background, emotion-aware robots will achieve great development. As a personated diversified intelligent agent, a robot can perform communication with users.

In recent years, some evaluable emotion perception models have been built for emotion–cognition and interaction [6–8]. Kaihao put forward a part-based hierarchical bidirectional recurrent neural network to analyze the facial expression information in

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time series. A multi-signal convolutional neural network was used to extract the spatial features from the stationary frames, which effectively improved the performance of facial expression recognition [4]. Z. Zhang deeply studied face images and designed an effective multi-task network to learn the face background information except for the facial expression. This network was mainly used to predict interpersonal relationships. The built model could effectively explore the mutual background of a face [6]. Besides the recognition of facial expression, Seunghyun put forward a novel deep double recursive encoder. The information of audio and text series was encoded. The two kinds of information were combined to predict the emotion type. The emotion types included anger, happiness, sadness, and neutrality [7,9,10]. Leila researched the classification of emotional states and modes of emotion expression, developed a voice and emotion recognition system based on different classifiers and different feature extraction methods, such as Mel-frequency cepstrum coefficients (MFCCs) and modulation spectral (MS) features, and researched the performance of different classifiers [8]. Therefore, it can be concluded that human facial expression and voice contain abundant emotion information. Thus, an intelligent robot with the emotion perception ability can recognize the user and help user adjust mood, strengthen active emotional interaction, and stimulate users' enthusiasm.

Recently, a lot of research has been devoted to the development of a robot with the emotion perception ability [11–13]. In [11], an emotion–cognition system was built and consolidated in the background of an intelligent learning environment. Based on certain learning motivation, a robot could cognize and adjust emotion to improve the performance of emotional interaction. However, the system is only help for making a decision for teaching; there was no emotional interaction with users. Fernando developed a social contact robot Maggie used for multi-modal user emotion detection. By analyzing voice and facial expression, emotion could be recognized; then, the dialog strategy was adjusted based on the result to make the user more satisfied [12]. Nevertheless, the robot Maggie was too large to be carried or follow users at any time. In addition, the emotion recognition model was universal, and it could difficultly meet personalized demand of different users. Gabriella regarded man-to-machine interaction as a special interaction. For instance, dog behavior was used as an inspiration to design the emotion expression behavior of a robot. This method could guide people to express their emotions [13]. Although the mode of interaction was simple, users' diversified demands could not be met.

Since the existing social and emotion perception robots have poor mobility and are too large to be carried, some wearable devices for emotion perception have been designed [14–16]. Jangho introduced a glass-type wearable system, where facial expression and physiological reaction were used by the system to judge user emotions [15,17]. Terence used a wearable biosensor to predict people emotions [14].

By summarizing the characters of common robots and wearable devices, it can be found that the existing systems have the following defects: (1) they are massive and thus not portable, so it is difficult to monitor user emotion in real-time; they cannot accompany their masters all the time to perceive and know their emotions; (2) the modality of perception data is simple, but limited to only user data, ignoring the environmental influence and influence of other people on user emotion; intelligent response cannot be provided during the interaction with users, only depending on a fixed database; (3) cognitive competence of robots cannot be upgraded; it is limited by computing power, and once being integrated, dynamic updating is difficult to be conducted.

Therefore, we propose a personal robot with the emotion–cognition ability based on wisdom clothing, referring to the advantages and defects of common robots and wearable devices. The proposed personal robot combines a wearable device and common robot, integrating the ability of communication, computing, and storage. Due to the emotion–cognition ability, it can give a wise response considering surroundings around its master. At the same time, it considers the emotional interaction between different users. The main contributions of this paper can be summarized as follows:

(1) Triune emotion–cognition framework, including the personal robot, smart clothing, and cloud terminal, is put forward. The characteristics of different devices are used to integrate resources of communication, computing, and storage, and cognize all-around user emotion and respond to user demand in real-time.
(2) The detailed principle of emotional perception and interaction is presented. Several functional modules are realized for environment perception, facial expression recognition, intelligent response, and intelligent recommendation to provide different personalized services.
(3) A testbed based on a personal robot, smart clothing, and the edge cloud is established, and a few tests are completed to estimate system performance. According to the test results, the proposed framework can meet the demand of emotion perception and emotional interaction.

The rest of the paper is organized as follows. Section 2 introduces the proposed triune emotion–cognition framework that includes the personal robot, smart clothing, and edge cloud [10]. Section 3 presents the design of the functional module for emotion perception. Section 4 provides research on cases of multiple scenarios. Section 5 establishes the testbed and discusses open issues. Section 6 summarizes the paper.

2. Overview of the architecture

Based on the discussion of emotion perception robots [14–16], the triune emotion–cognition framework, including the personal robot, smart clothing, and edge cloud, is put forward, and it is shown in Fig. 1. The framework consists of three parts, namely data-aware engine, emotion–cognition engine, and edge network for realizing the interaction between them. Each of the parts is introduced in the following.

2.1. Data-aware engine

The data-aware engine is a module that is directly responsible for interacting with a user in different environments. It contains two parts, personal robot, and smart clothing. The emotion interaction with a user can be completed in different scenarios and environments.

2.1.1. Role positioning of personal robot

Usually, a personal robot is placed in a fixed site (such as a home) for the purpose of data perception, model training, and learning because it is large and not portable. The perceived data types are as follows.

- Household environmental data. When a personal robot is placed in the environment of a smart home, it can continuously collect a large amount of data by program interface and sensors produced by the smart home appliances. The data can be logs or data of early warning. At the same time, the robot can process the structural data. By analyzing and processing the data, a visualized graph can be generated for