Paper:

Quantum Representation for Robot's Emotions Based on PAD Model

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Abstract: The development line of robotics is marked with the triad: industrial–assistive–social robots, which leads from human-robot separation toward human-robot interaction (HRI). Exploiting the promise of security and efficiency that quantum computing offers, a quantum representation based on the Pleasure-Arousal-Dominance (PAD) emotion model (QRPE) is proposed, which utilizes only $n+3$ qubits to store robot emotions in a time cycle. Meanwhile, an example to illustrate quantum robot emotional state is given. Furthermore, three unitary operations that can be performed on the QRPE model to achieve specific transitions are designed. They facilitate the construction of complex quantum algorithms to deal with robot's emotions and the improvement of robot's ability to provide better service to humans.

Keywords: quantum computing, human-robot interaction, robot's emotions, PAD emotion model

1. Introduction

As humanoid robots become social companions inhabiting and building relationship with humans, the study of the emotional communication between humans and robots are increasing in the field of human-robot interaction (HRI). Such socially assistive robots are increasingly used in nursing homes as a companion providing for elderly or autistic people with mental health services, which can help relieving loneliness and enabling communication [1]. In this situation, artificial emotions help robots drive cognitive mechanisms for selecting appropriate actions in response to environmental stimuli, which have been explored and modeled to promote interactions between humans and robots. Therefore, various models have been proposed to establish the emotional states of robots, such as Ekman's six basic emotions [2], "Plutchik" emotions wheel [3], Izard's four-dimensional theory [4], and Pleasure-Arousal-Dominance (PAD) emotional state model [5]. Among them, the PAD model has been extensively applied to text semantics [6], audiovisual speech [7], head and facial gestures [8], and emotional description of emotional expression robots [9].

With the rapid development of quantum computing, the combination of emotion models and quantum computing will greatly promote the development of emotional computing. In recent years, there are some attempts, e.g., applying quantum circuits to fuzzy set modeling [10], quantum emotion representation based on the Bloch sphere [11], computational description of a quantum mixed state composed of emotions and thoughts [12], and describing and manipulating the emotion space of robots, extending emotional interpretation to the field of quantum computing [13].

In this study, a quantum representation based on the PAD emotion model (QRPE) is proposed. Three qubits are allocated to determine the type of emotions, the angle information of three entangled qubits is used to represent the three-dimensional emotional information, and a n-qubits sequence is used to determine the time. Moreover, three operations are designed to transform emotions for specific application.

The rest of this study is organized as follows. In Section 2, the QRPE model and its preparation procedure are discussed, which is transformed from the initialization state to the QRPE state. In addition, a simple example is given to shown the robot's emotional state over a period of time. In Section 3, three operations for QRPE are designed to manipulate the emotions of robots. Meanwhile, examples are given to illustrate these operations.

2. Quantum Representation Based on PAD Emotion Model

Based on the PAD emotion model, QRPE model and the emotions generation of robot are introduced in this section.

2.1. Modified PAD Emotion Model

The commonly used PAD emotion model expresses emotions according to the three-dimensional scale, where P (Pleasure-Displeasure) represents the individual emotional state (i.e., positive and negative characteristics); A (Arousal-nonarousal) represents the individual's neurophysiological activation level, alertness. It is related to the activation degree of the body energy associated to the emotional state; and D (Dominance-Submissiveness) represents the individual's situation and control of others. In such case, the robot's emotions can be mapped to a three-dimensional coordinate of the PAD emotion space [14] as shown in **Figure 1**.

Specifically, in the PAD emotion model, eight areas (i.e., Q_a, Q_b, Q_c, Q_d, Q_e, Q_f, Q_g, and Q_h) filled with

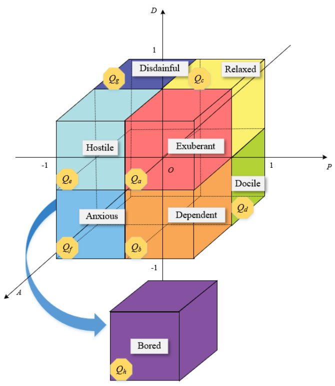

Fig. 1. Emotion octants of the PAD space.

different colors are used to represent eight emotion labels (i.e., Exuberant, Dependent, Relaxed, Docile, Bored, Disdainful, Anxious, and Hostile) as shown in Table 1.

Table 1. Emotional label of the PAD space.

Quadrant	Label	Quadrant	Label
Q_a(+P+A+D)	Exuberant	Q_h(-P-A-D)	Bored
Q_b(+P+A-D)	Dependent	Q_g(-P-A+D)	Disdainful
Q_c(+P-A+D)	Relaxed	Q_f(-P+A-D)	Anxious
Q_d(+P-A-D)	Docile	Q_e(-P+A+D)	Hostile

2.2. QRPE Model

In order to express the robot's emotions over a period of time on quantum computers, the QRPE is presented as

$$|R_{QRPE}\rangle = \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2}^n}\sum_{t=0}^{2^n-1}|E^t_{PAD}\rangle \otimes |t\rangle, \quad (1)$$

which can be composed by two parts: emotional information $|E^t_{PAD}\rangle$ and the corresponding time cycle $|t\rangle = |t_{n-1}t_{n-2}...t_0\rangle$. Specifically, emotional information can be mathematically defined as

$$\begin{aligned}|E^t_{PAD}\rangle &= (\cos\frac{\theta^t_P}{2}|0\rangle + \sin\frac{\theta^t_P}{2}|1\rangle)|01\rangle + (\cos\frac{\theta^t_A}{2}|0\rangle \\ &+ \sin\frac{\theta^t_A}{2}|1\rangle)|10\rangle + (\cos\frac{\theta^t_D}{2}|0\rangle + \sin\frac{\theta^t_D}{2}|1\rangle)|11\rangle \\ &= \cos\frac{\theta^t_P}{2}|001\rangle + \cos\frac{\theta^t_A}{2}|010\rangle + \cos\frac{\theta^t_D}{2}|011\rangle \\ &+ \sin\frac{\theta^t_P}{2}|101\rangle + \sin\frac{\theta^t_A}{2}|110\rangle + \sin\frac{\theta^t_D}{2}|111\rangle.\end{aligned} \quad (2)$$

In **Equation (2)**, $|E^t_{PAD}\rangle$ is composed of six computational basic states $|001\rangle$, $|010\rangle$, $|011\rangle$, $|101\rangle$, $|110\rangle$, and $|111\rangle$ with their probability amplitudes. The superposition state $\cos\frac{\theta_X}{2}^t|0\rangle + \sin\frac{\theta_X}{2}^t|1\rangle$ ($X = \{P,A,D\}$ and $\{\theta^t_P, \theta^t_A, \theta^t_D\} \in [0,\pi]$) are used to determine the dimension of emotions.

The emotional states of a robot in a certain time cycle ($t = 4$) in QRPE model is shown in **Figure 2**, where three qubits are used to represent the emotional information based on PAD model at each moment, and the other two qubits are encoded to describe the required time information.

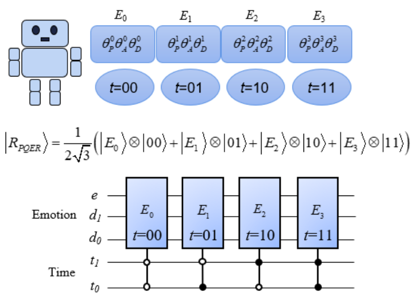

Fig. 2. An example of the robot in QRPE model.

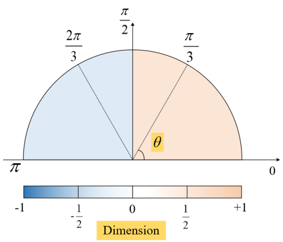

Fig. 3. Correspondence between angles and emotion space.

The relationship between the emotion space of dimension and angle value θ^t_X, where $X = \{P,A,D\}$, is defined as shown in **Figure 3**. Since $\theta \in [0,\pi]$, it is determined that the angle range of the positive semi-axis mapping is $[0,\frac{\pi}{2})$, and the angle range of the negative semi-axis is $(\frac{\pi}{2},\pi]$. When $\theta = \frac{\pi}{2}$, it means that the value of the dimension is 0.

2.3. QRPE Generation Procedure

To achieve the transforming of quantum states from the initial state to the desired QRPE model, several quantum gates (identity, Hadamard, and rotation) are required to obtain the desired QRPE state. Given three angle vectors $\theta_X = (\theta^0_X, \theta^1_X, ..., \theta^{2^n-1}_X), (\theta \in [0,\pi], X = \{P,A,D\})$, assume that the initial state is $|0\rangle^{\otimes n+3}$, where n is the number of qubits carrying time information, and 3 qubits are used to encode emotional information. After multi-step unitary transformation, the initial state of the quantum computer is transformed into the state required by QRPE. The transformation is mainly completed by the following three steps.

As a preliminary, three operators are designed as follows to transform the initial state:

$$M_x(\arctan\sqrt{2}) = \begin{pmatrix}\cos(\arctan\sqrt{2}) & \sin(\arctan\sqrt{2}) \\ \sin(\arctan\sqrt{2}) & -\cos(\arctan\sqrt{2})\end{pmatrix}, \quad (3)$$

$$M_A = |0\rangle\langle 0|\otimes X + |1\rangle\langle 1|\otimes I, \quad (4)$$

$$M_B = |0\rangle\langle 0|\otimes I + |1\rangle\langle 1|\otimes H. \quad (5)$$

Step 1: The transform $\mathscr{T} = |I\rangle^{\otimes 3} \otimes H^{\otimes n}$ is designed by the tensor product of three identity and n Hadamard matrices, which can be used to transform the initial state $|0\rangle^{\otimes 3+n}$ to an intermediate state as

$$\begin{aligned} |H\rangle &= \mathscr{T}(|0\rangle^{\otimes n+3}) \\ &= I^{\otimes 3}|0\rangle^{\otimes 3} \otimes |H\rangle^{\otimes n}|0\rangle^{\otimes n} \\ &= \frac{1}{\sqrt{2}^n}\sum_{t=0}^{2^n-1}|0\rangle^{\otimes 3}\otimes|t\rangle. \end{aligned} \quad (6)$$

Step 2: The time information has been initialized, then the transform $\mathscr{M} = I\otimes M(B)M(A)M(x)\otimes I$ is considered to transform the $|0\rangle^{\otimes 3}$ to the emotional state of QRPE (i.e. $|E_{PAD}\rangle$), which can be described as

$$\begin{aligned} |E_{PAD}\rangle &= \mathscr{M}|0\rangle^{\otimes 3} \\ &= I|0\rangle \otimes M(B)M(A)[\cos(\arctan\sqrt{2})|0\rangle + \\ &\sin(\arctan\sqrt{2})|1\rangle]\otimes I|0\rangle \\ &= I|0\rangle\otimes M(B)[\cos(\arctan\sqrt{2})|01\rangle + \sin(\arctan\sqrt{2})|10\rangle] \\ &= |0\rangle\otimes[\cos(\arctan\sqrt{2})|01\rangle + \frac{1}{\sqrt{2}}\sin(\arctan\sqrt{2})|10\rangle + \\ &\frac{1}{\sqrt{2}}\sin(\arctan\sqrt{2})|11\rangle] \\ &= \frac{1}{\sqrt{3}}|0\rangle\otimes(|01\rangle+|10\rangle+|11\rangle). \end{aligned} \quad (7)$$

Step 3: When the robot is motivated by stimulation, the emotions in the period $|t\rangle$ can be generated by three rotation matrices (rotation θ around the y-axis of the Bloch sphere), which is defined as

$$R_y(\theta) = \begin{pmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{pmatrix}, \theta = \left\{\theta_P^t, \theta_A^t, \theta_D^t\right\}. \quad (8)$$

Based on the transformation in **Equation (8)**, three control rotation matrices θ_P^t, θ_A^t, and θ_D^t are given as

$$\begin{cases} R_t^P = I\otimes\sum_{j=2}^{3}|j\rangle\langle j| + R_y(\theta_P^t)\otimes|1\rangle\langle 1|, \\ R_t^A = I\otimes\sum_{j=1,j\neq 2}^{3}|j\rangle\langle j| + R_y(\theta_A^t)\otimes|2\rangle\langle 2|, \\ R_t^D = I\otimes\sum_{j=1,j\neq 3}^{3}|j\rangle\langle j| + R_y(\theta_D^t)\otimes|3\rangle\langle 3|. \end{cases} \quad (9)$$

Therefore, $R_t' = R_t^D R_t^A R_t^P$. Then the operation R_t, $t = \{0,1,\ldots,2^n-1\}$ can be formalized as

$$R_t = I^{\otimes 3}\otimes\sum_{j=1,j\neq t}^{2^n-1}|j\rangle\langle j| + R_t'\otimes|t\rangle\langle t|. \quad (10)$$

It is clear that R_t is a unitary matrix since $R_t R_t^\dagger = I^{\otimes n+3}$.

$$\begin{aligned} R_m R_k(|E_{PAD}\rangle|H\rangle) &= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2}^n}\Bigg(|0\rangle\otimes\sum_{l=1}^{3}|l\rangle\otimes\sum_{j=0,j\neq k,m}^{2^n-1}|j\rangle \\ &+ |E_{PAD}^k\rangle\otimes|k\rangle + |E_{PAD}^m\rangle\otimes|m\rangle\Bigg) \\ &= |R_{QRPE}\rangle. \end{aligned} \quad (11)$$

After the transformations above, the initialized state $|0\rangle^{\otimes 3+n}$ is transformed to the QRPE state as shown in **Figure 4**. The complexity of the preparation for $|R_{QRPE}\rangle$ can be calculated in terms of quantum gates. As such, the complexity of $|R_{QRPE}\rangle$ can be calculated as

$$\begin{aligned} &(n+5) + 3\times 2^n\times(2^{2n+2}-1) + 3\times 2^n\times(2^{2n+2}-2) \\ &= 3\times 2^{3n+3} - 9\times 2^n + n + 5. \end{aligned} \quad (12)$$

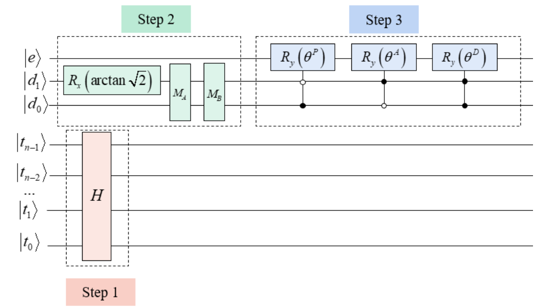

Fig. 4. General circuit of QRPE model.

2.4. Measurement-Based Emotions Retrieval

The measurement of the quantum state of robot's emotions is used to retrieve the probability distribution of emotions. The emotional information of QRPE is presented as follows:

$$\begin{aligned} |E_{PAD}^t\rangle &= \cos\frac{\theta_P^t}{2}|001\rangle + \cos\frac{\theta_A^t}{2}|010\rangle + \cos\frac{\theta_D^t}{2}|011\rangle \\ &+ \sin\frac{\theta_P^t}{2}|101\rangle + \sin\frac{\theta_A^t}{2}|110\rangle + \sin\frac{\theta_D^t}{2}|111\rangle. \end{aligned} \quad (13)$$

Therefore, in order to retrieve the emotion information of the robot, the coefficient of this state needs to be measured separately. The emotional state can be written as

$$|E_{PAD}^t\rangle = |E_P\rangle|01\rangle + |E_A\rangle|10\rangle + |E_D\rangle|11\rangle, \quad (14)$$

where

$$\begin{cases} |E_P\rangle = \cos\frac{\theta_P^t}{2}|0\rangle + \sin\frac{\theta_P^t}{2}|1\rangle, \\ |E_A\rangle = \cos\frac{\theta_A^t}{2}|0\rangle + \sin\frac{\theta_A^t}{2}|1\rangle, \\ |E_D\rangle = \cos\frac{\theta_D^t}{2}|0\rangle + \sin\frac{\theta_D^t}{2}|1\rangle. \end{cases} \quad (15)$$

According to **Equations (14) and (15)**, the measurement operation is retrieved in emotional dimensions. Therefore, $|E_P\rangle$ encodes the value of the P dimension, $|E_A\rangle$ encodes the value of the A dimension, and $|E_D\rangle$ encodes the value of the D dimension. The qubits d_1 and d_0 are used to control the operation, respectively. In theory, every measurement result on $|E_X\rangle(X = \{P,A,D\})$ is 0 or 1. When the measurement result is 0, the probability is $\cos^2\frac{\theta_X^t}{2}$. Otherwise, the probability is $\sin^2\frac{\theta_X^t}{2}$. Then the X dimension value can be obtained by the probability.

A simple example is given to show the robot's emotional state in a time cycle. The specific emotional state

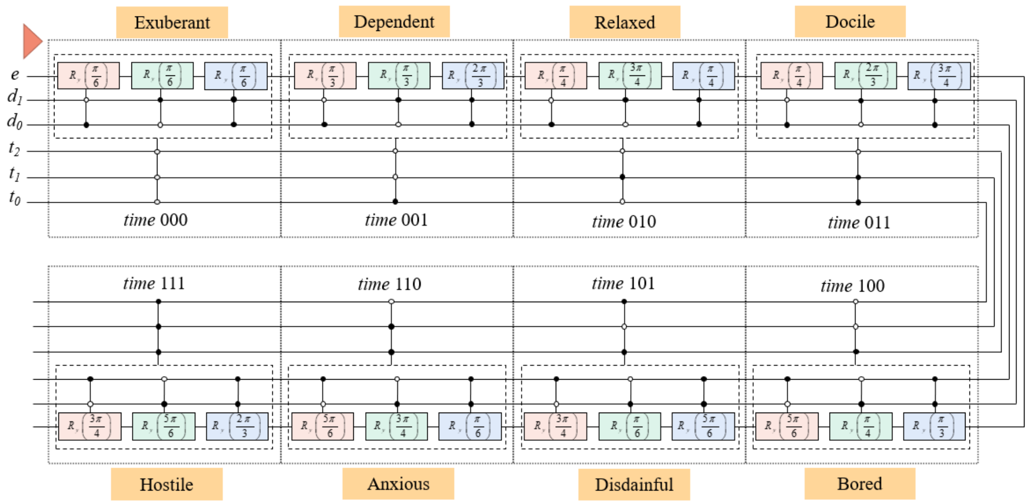

Fig. 5. Quantum circuit to encode emotions in a time cycle to QRPE model.

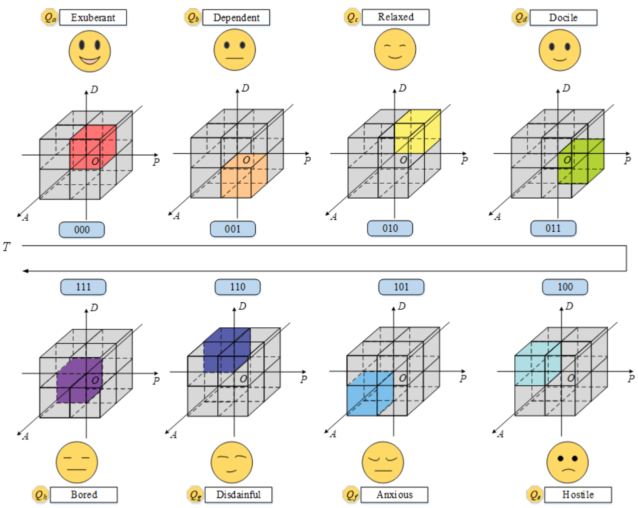

Fig. 6. Robot's emotional state in a time cycle.

at the corresponding time is shown in **Figure 6**. It can be implemented by the quantum circuit in **Figure 5**.

As mentioned earlier, the angle information encoded by three emotions is used to represent changing emotions, and four qubits are used to represent time information. An example is used to illustrate the emotional state (from quadrant a to h) of the robot in QRPE model over a time cycle (from 1 to 8), which is given in **Figure 6**.

3. Operations on QRPE Model

Based on the above discussion, the emotions of a robot in a period are encoded in QRPE model, quantum operations performing on QRPE to achieve changing dimensional emotion (CDE), dimension swapping (DS), and time reversal (TR) are designed in this section.

3.1. *CDE* Operation

The CDE operations including CDE_P, CDE_A, and CDE_D are applied on the three dimensions (P, A, and D), respectively. Therefore, the emotionnal information will be changed in only one dimension or multi-dimensions by changing the angle information with control additions (i.e., dimensions). The operator can be defined as

$$CDE_X = I^{\otimes 3} \otimes \sum_{t=0,t\neq k}^{2^n-1} |t\rangle\langle t| + ET_X \otimes |k\rangle\langle k|, \quad \ldots \quad (16)$$

where the operator ET_X is realized by using the $U_X = C^2R_y(\theta)$ gate as shown in **Figure 7**, which can be mathematically described as

$$ET_X = U_X \otimes I^{\otimes n}, X = \{P, A, D\}. \quad \ldots \quad (17)$$

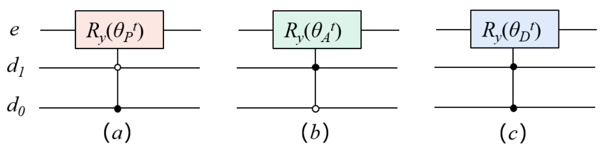

Fig. 7. Circuit to implement the U_X operation.

Applying the CDE_X operator on the QRPE in **Equation (1)** will yield

$$\begin{aligned}
&CDE_X|R^t_{QRPE}\rangle \\
&= CDE_X\left(\frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\sum_{t=0}^{2^n-1}|E^t_{PAD}\rangle\otimes|t\rangle\right) \\
&= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\left(\sum_{t=0,t\neq k}^{2^n-1}|E^t_{PAD}\rangle\otimes|t\rangle + ET_X\sum_{t=0}^{2^n-1}|E^k_{PAD}\rangle\otimes|k\rangle\right) \\
&= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\left(\sum_{t=0,t\neq k}^{2^n-1}|E^t_{PAD}\rangle\otimes|t\rangle + (U_X\otimes I^{\otimes n})\sum_{t=0}^{2^n-1}|E^k_{PAD}\rangle\otimes|k\rangle\right) \\
&= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\left(\sum_{t=0,t\neq k}^{2^n-1}|E^t_{PAD}\rangle\otimes|t\rangle + \sum_{t=0}^{2^n-1}|E^{k'}_{PAD}\rangle\otimes|k\rangle\right).
\end{aligned} \quad (18)$$

The rotation angle is controlled by the emotional dimension as shown in **Equation (19)**. The circuit of controlled-rotation gates for d_1 and d_0 is shown in **Figure 7**.

$$\begin{cases} |E^{P}_{PAD}\rangle = \cos(\frac{\theta^t_P-\theta}{2})|001\rangle + \cos\frac{\theta^t_A}{2}|010\rangle + \cos\frac{\theta^t_D}{2}|011\rangle \\ \qquad + \sin(\frac{\theta^t_P-\theta}{2})|101\rangle + \sin\frac{\theta^t_A}{2}|110\rangle + \sin\frac{\theta^t_D}{2}|111\rangle, \\ |E^{A}_{PAD}\rangle = \cos\frac{\theta^t_P}{2}|001\rangle + \cos(\frac{\theta^t_A-\theta}{2})|010\rangle + \cos\frac{\theta^t_D}{2}|011\rangle \\ \qquad + \sin\frac{\theta^t_P}{2}|101\rangle + \sin(\frac{\theta^t_A-\theta}{2})|110\rangle + \sin\frac{\theta^t_D}{2}|111\rangle, \\ |E^{D}_{PAD}\rangle = \cos\frac{\theta^t_P}{2}|001\rangle + \cos\frac{\theta^t_A}{2}|010\rangle + \cos(\frac{\theta^t_D-\theta}{2})|011\rangle \\ \qquad + \sin\frac{\theta^t_P}{2}|101\rangle + \sin\frac{\theta^t_A}{2}|110\rangle + \sin(\frac{\theta^t_D-\theta}{2})|111\rangle. \end{cases} \quad (19)$$

It should be noted that the emotion $|E^k_{PAD}\rangle$ in **Equation (18)** at time $|k\rangle$ has all of its emotion coming from the original emotion $|E_{PAD}\rangle$ by shifting the angle θ on the P, A, or D dimension.

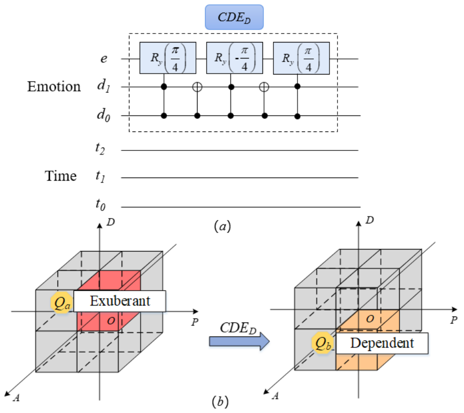

Fig. 8. Circuit to implement the CDE_D operation.

Figure 8(a) is the circuit diagram of CDE_D. By controlling conditions d_1 and d_0, the CDE operation changes the value of dimension D. **Figure 8(b)** shows the emotion transforming from Q_a to Q_b, which is realized by CDE_D.

3.2. *DS* Operation

The DS operations is DS_Y ($Y = \{PA, PD, AD\}$). These operations exchange emotional dimension values between P and A; P and D; A and D dimensions, respectively, where $DS_Y = I \otimes U_Y \otimes I^{\otimes n}$ is used to act on d_1 and d_0. The DS_Y applied on $|R_{QRPE}\rangle$ can be described as

$$\begin{aligned} DS_Y(|R_{QRPE}\rangle) &= (I \otimes U_Y \otimes I^{\otimes n})|R_{QRPE}\rangle \\ &= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\sum_{t=0}^{2^n-1}|E^{Y_t}_{PAD}\rangle \otimes |t\rangle, \quad . \quad . \quad . \quad (20) \\ &= |R^{Y}_{QRPE}\rangle \end{aligned}$$

where $|E^{Y_t}_{PAD}\rangle$ is the new emotional state after the DS_Y operation, the transformation process can be mathematically expressed as

$$\begin{cases} |E^{PA_t}_{PAD}\rangle = \cos\frac{\theta^t_A}{2}|001\rangle + \cos\frac{\theta^t_P}{2}|010\rangle + \cos\frac{\theta^t_D}{2}|011\rangle \\ \qquad + \sin\frac{\theta^t_A}{2}|101\rangle + \sin\frac{\theta^t_P}{2}|110\rangle + \sin\frac{\theta^t_D}{2}|111\rangle, \\ |E^{PD_t}_{PAD}\rangle = \cos\frac{\theta^t_D}{2}|001\rangle + \cos\frac{\theta^t_A}{2}|010\rangle + \cos\frac{\theta^t_P}{2}|011\rangle \\ \qquad + \sin\frac{\theta^t_D}{2}|101\rangle + \sin\frac{\theta^t_A}{2}|110\rangle + \sin\frac{\theta^t_P}{2}|111\rangle, \\ |E^{AD_t}_{PAD}\rangle = \cos\frac{\theta^t_P}{2}|001\rangle + \cos\frac{\theta^t_D}{2}|010\rangle + \cos\frac{\theta^t_A}{2}|011\rangle \\ \qquad + \sin\frac{\theta^t_P}{2}|101\rangle + \sin\frac{\theta^t_D}{2}|110\rangle + \sin\frac{\theta^t_A}{2}|111\rangle. \end{cases} \quad (21)$$

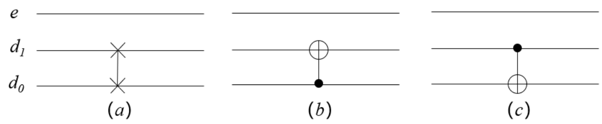

Fig. 9. Circuit to implement the U_Y operation.

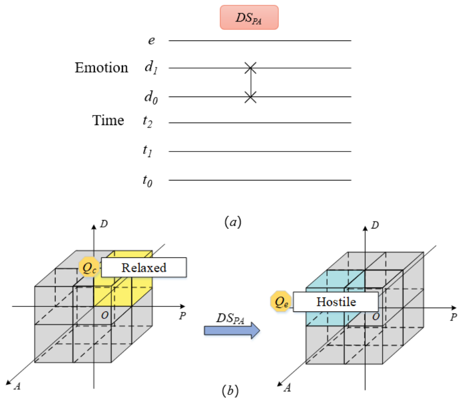

Fig. 10. Circuit to implement the DS_{PA} operation.

Quantum state $|R^{Y}_{QRPE}\rangle$ is obtained by performing the DS_Y operation on the original state $|R_{QRPE}\rangle$. Specifically, the quantum circuit of $U_Y(U_{PA}, U_{PD}, U_{AD})$ are shown in **Figure 9**. **Figure 10(a)** is the circuit diagram of DS_{PA}. By swapping d_1 and d_0, the DS operation exchanges the values of the two dimensions. **Figure 10(b)** shows the change of emotions from Q_c to Q_e.

3.3. *TR* Operation

In order to realize the human-computer interaction, returning to the last emotion is required in the previous layer, that is, the emotion of the last moment. Thus, the TR operator is designed to realize this operation. The time label is the unique identifier of the changed emotions. In order to change the output emotional sequence back to the previous moment, the time label should be changed by the TR operator. The notation t is the time information of the QRPE model, s is the difference between t and $(t \pm s)$.

The operator that acts on the $|QRPE\rangle$ can be expressed as

$$\begin{aligned} TR|R_{QRPE}\rangle &= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\sum_{t=0}^{2^n-1}|E_{PAD}^{t}\rangle \otimes TR_s|t\rangle \\ &= \frac{1}{\sqrt{3}}\frac{1}{\sqrt{2^n}}\sum_{t=0}^{2^n-1}|E_{PAD}^{t\pm s}\rangle \otimes |t \pm s \mod 2^n\rangle. \end{aligned} \quad (22)$$

For the same situation, the emotion expression of the robot can directly extract the generated emotions. The operation can be applied flexibly in the face of some common situations.

As mentioned above, by combining multiple emotional states of the robot into a unit, the different emotional states are cut and merged. Therefore, the function of the TR operation can be used to realize the combination and expression of the robot's emotional changes. In this case, the emotional state of each emotional dimension will be replaced.

4. Conclusions

A quantum robot's emotions representation based on PAD model (QRPE) is presented in this study. Specifically, the process of QRPE preparation and transformation; generation of robot's emotions in QRPE model; emotions retrieval based on measurement; and a simple example to show the emotional state in a time period are discussed. Based on these, some operations on robot's emotional information and corresponding examples are designed, which provide a certain foundation for realizing the processing of quantum robot's emotions.

The fusion of different technology and robotics are striving to come up with new advancements, which will enhance civilization and ultimately improve the quality of life. In the future work, this study may be able to promote emotion cognitive by employing quantum algorithms, such as quantum machine learning [16] and reinforcement learning [17]. To accommodate the advancement of the companion robot, more comprehensive QRPE models can be built to describe more types of robot's emotions to improve the service and communication ability of the companion robot.

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