EMO-SPACE: A COMPUTATIONAL MODEL FOR INTERACTION BETWEEN EMOTIONS AND SPACE

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Abstract. Architectural space can trigger emotion (Zumthor, 2006). Psychologists Mehrabian and Russell (1974) proposed PAD model, presenting eight emotions as a means for psychologists to self-assess the emotional conditions of human experience and to provide people with a way to conceptualize the impact of cognitive structure. The Brain-Computer Interface (BCI) combines with computer operations to decode and calculate different brain waves generated by human emotions, supporting the convenience and wisdom of human life. The integration of the PDA model and BCI technology will offer an understanding of the interactive relationships between space and emotion. The purpose of this research is to construct a computational model called EMO-Space, which can autonomously support space interaction through the understanding of human emotions. Based on the PAD model, the integration of BCI, the mechanism of emotional transformation, and the control of message transmission are explored. Subsequently, the computational model is proposed and simulated. EMO-Space will provide the basis for the intelligence of emotional space in the future, such as in elderly care and spatial healing.

Keywords. Emotional space, Emotion, Interaction, BCI, Computational model

1. Introduction

Humans are accustomed to placing their bodies in three-dimensional space. Through the intervention of the body, they can generate different emotions towards the space and then communicate with architecture and environment (Bloomer, et al., 1997). The renowned Swiss architect Peter Zumthor (2006) emphasized the importance of connection between the human emotions and spatial experience, which he called atmosphere. However, from Modernism's focus on function and efficiency to pursuing speed and form generation in the digital era, the consideration of emotions in architectural design has been gradually ignored (Lefebvre, 1992). This ignorance will lead to the insensitivity of human beings' reactions to the design of space and environment. Under the current trend of accelerating design, we need to return to our bodies and rethink "the interactive relationships between space and emotions ", which would be an important issue in the realm of architectural design and design education.

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While it is possible to understand human emotions through facial expressions (Ekman, 1986), it certainly has its limitations, such as in patients with psychological problems where a smiling face may not necessarily represent joy, or when the face is covered by masks during an epidemic. Psychologists Mehrabian and Russell (1974) proposed the PAD model and eight emotions as a way for psychologists to self-assess the emotional structure of experience and provide people with a way to conceptualize the impact on cognitive structure. Additionally, digital technology enables real-time feedback and information transmission dynamically. The Brain-Computer Interface (BCI) such as EmotivBCI combines with computer operations to decode and calculate different brain waves generated by human emotions to support the convenience and wisdom of human life. Thus, the integration of the PDA model and BCI technology will provide us with an understanding of the interactive relationships between space and emotion.

The purpose of this research is to construct a computational model called EMO-Space, which can support space to interact intelligently through understanding human emotions autonomously. Our research steps are as follows: 1) study the relationships among emotions, space, and BCI interactive technology through literature reviews; 2) construct a computational model called EMO-Space based on a computational approach, which includes the mechanism of emotional transformation, the control of message transmission, and implementation by combining Python software with Arduino hardware; 3) conduct a design experiment to test and simulate the operation of EMO-Space ; 4) finally, use an example to describe its application. This computational model will provide the basis for the intelligence of emotional space in the future, such as in elderly care and spatial healing.

2. Previous Research

2.1. PAD, AN EMOTIONAL MODEL

In the field of emotional psychology, numerous researchers have developed various types of emotional models, such as the PANA model (1985) and the Plutchik model (1982). The PAD model, initially proposed by psychologists Mehrabian and Russell (1974), is the first to utilize mathematical vectors to describe the quantitative relationships in the three-dimensional space of emotions. This model primarily subdivides emotions into three indicators, which serve as evaluation factors for individuals to regulate emotional states. These indicators include Pleasure (P-N emotion, presenting positive and negative emotions), Arousal (the activation degree of emotion), and Dominance (subjective and objective aspects, as well as the controllable degree of emotion). Based on the three indicators, the resulting three-dimensional emotional model can be applied to the study of non-verbal communication, such as body language and emotional expression in psychology.

In the three-dimensional emotional model PAD (Figure 1), the dimensions (X, Y, Z) of the three indicators (Pleasure-Arousal-Dominance) respectively correspond to eight emotional states (Joyful, Surprised, Fear, Angry, Satisfied, Protect, Sad, Unconcerned). Through the indicators and their corresponding emotions, each indicator is quantified and assessed to determine the prevailing emotional states at that time. The PAD model serves as a crucial reference for the mathematical quantification of current emotional models. Therefore, this study will utilize the PAD model as the foundation for constructing a computational model of emotional space.

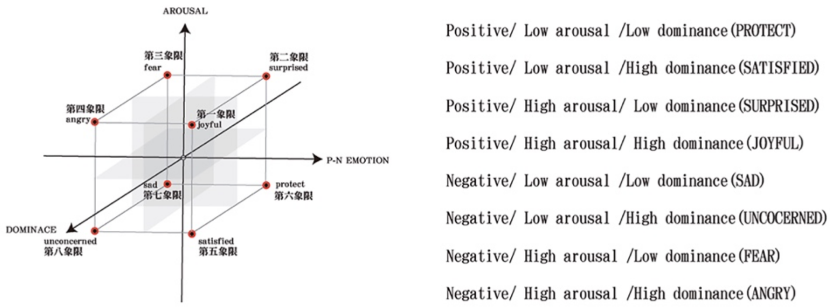

Figure 1. PAD Model, three indicators and eight emotional states

2.2. EMOTION AND SPACE

In the book "Atmosphere" (2006), the renowned Swiss architect Peter Zumthor employs the term atmosphere to emphasize the importance of relationships between emotion and space through human perceptions. Xia (2019) asserts that emotions possess controllable, adjustable, creative, and dismantling characteristics. By manipulating spatial elements and altering spatial materials, various emotional states of individuals can be adjusted. For instance, in the shape of space, the circles evoke a sense of ease, triangles induce anxiety, flower shapes elicit happiness, and square shapes promote stability. Additionally, the openness of space is connected to light; bright spaces generate feelings of happiness, while dark spaces induce relaxation.

Architectural has the potential to evoke emotions. Space is constructed through the walls, floors, columns, openings, etc. of the building. Ultimately, human emotions are triggered through the embodied experience within the space. Many architects utilize openings and shapes to create a spatial atmosphere, allowing users to experience the spatial tension, as exemplified by the Jewish Museum Berlin designed by architect Daniel Libeskind (Figure 2). Huelat (2019) contends that people's emotions can be enhanced through space shaping, leading to the attainment of healing space in the transition from negative emotions to positive emotions. Xia (2019) also posits that, regardless of our current emotional state, our emotions can be improved by modifying the elements of the space we inhabit.

Figure 2. The Jewish Museum Berlin designed by architect Daniel Libeskind

2.3. EMOTION AND INTERACTION

There are some limitations to understand human emotions through facial expressions such as patients with psychological problems where a smiling face may not necessarily represent joy, or when the face is covered by masks during an epidemic. Through decoding and calculating different brain waves, the Brain-Computer Interface (BCI) can provide communication link between emotions and spaces. The measurement method of BCI can divided into invasive, partially invasive, and non-invasive. The invasive signal has the highest quality, but it will cause wounds on the head, and the signal will gradually decline over time. The partially invasive implant electrode is shallower, and the quality is between invasive and non-invasive. The non-invasive uses conductive glue on the head for brain waves detection.

BCI applications include 1) to help patients with neuromuscular system disorders to rebuild their ability to control functions (Belkacem et.al, 2020); 2) to help individuals to freely control movement of robotic arms through brain waves (Rosca and Leba, 2017); 3) and to allow users to experience the real feeling of concentration and relaxation many times in games, and then understand how they are in a focused state (Prapas et al., 2023). Considering the safety of use and the accessibility of software interface operation and development, we chose the non-invasive EPOC BCI developed by Emotiv as the device to approach the study. EPOC has 16 detective points of brain waves combined with six indicators to judge emotional states. The six indicators include stress (FRU), engagement (ENG), interest (VAL), excitement (EXC), concentration (FOC), and relaxation (MED), which will provide our understanding the relationships between emotions and space.

3. EMO-Space: A Computational Model

The purpose of this research is to construct a computational model of the interaction between emotion and space (called EMO-Space), which is completed in three steps: 1) to integrate the PAD three-dimensional emotion model (including three indicators and eight emotions) and the six emotion parameters of EPOC indicators; 2) to find the rules and mechanisms of message transmission for various transformation processes between positive emotions and negative emotions; 3) finally, to integrate Python and Arduino, a computational model is constructed. EMO-Space will provide users to have the dynamic interaction between space and emotions under different spatial conditions and human experience.

3.1. INTEGRATION OF PAD MODEL AND EPOC INDICATORS

Based on the description of emotions by the six indicators of EPOC (https://www.emotiv.com), and with reference to the definition of the three dimensions (X, Y, Z) and emotional states in the PAD Model, we think that the positive and negative directions of PAD (Pleasure-displeasure) are the same as the interest (VAL) of EPOC. Both serve as a distinction between good and bad emotions. PAD activation level (Arousal-nonarousal) relates to EPOC participation (ENG) and focus (FOC). They express the judgment of the concentration and alertness corresponding to a thing. PAD subjective and objective level (Dominance-submissiveness) and EPOC excitement (EXC) are alike based on the degree of physiological and emotional control. Therefore, we use the above four EPOC indicators as the main criteria for emotional judgment. Relaxation (MED) and stress (FRU) are additional inspection indicators. By examining the numerical changes in the degree of relaxation (MED) and stress (FRU), we can employ them as references to find if the final emotional state "Satisfied" is arrived (Figure 3).

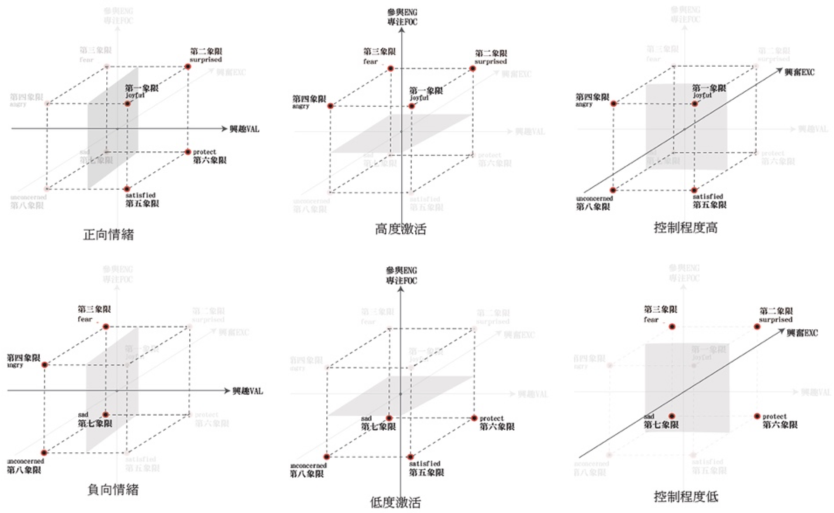

Figure 3. Integration of PAD model and EPOC indicators

3.2. TRANSFORMATION MECHANISMS AND MESSAGE TRAMISSION

Russell (1980) believes that the change between various emotions is the process of gradual transformation between positive emotions and negative emotions. This process is the result of the interaction of three indicators in the PAD model. To construct a computable emotion model, this study selects a single emotion change for observation each time, which facilitates the discovery of clear paths and indicator relationships of emotion changes. Basically, the values of six EPOC indicators are between 0 and 1. Through mapping the numerical distribution of the 6 psychological states within EPOC to the 8 emotional states within the PAD model, the transformation mechanisms are proposed.

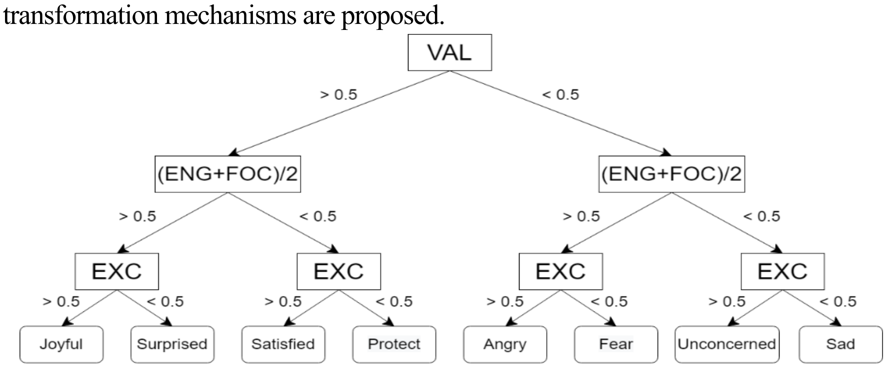

Figure 4. Decision Trees of EMO-Space

To control the message transmission among 8 emotional states of PAD and 4 main indicators of EPOC, we utilize the algorithm "Decision Tree" as the emotion classification method and take value 0.5 as the threshold. First, the Decision Tree determines whether the Interest (VAL) is greater than 0.5. Then, Engagement (ENG) and Focus (FOC) are added and divided by 2 to determine whether it is greater than 0.5. Finally, it is determined whether Excitement (EXC) is greater than 0.5. Through this tree structure, 8 emotional states can be classified (Figure 4).

3.3. IMPLEMENTATION OF THE COMPUTATION MODEL

EMO-Space mainly detects whether the user's emotional state is "Satisfied" through EPOC, which is used as the basis for judging the termination of spatial changes. To make EMO-Space achieve the emotional state "Satisfied" suitably and effectively, the implementation of the computational model is divided into two stages. In the first stage, when the user wears the EPOC, the received data of brain waves will be sent to the computer. After analysis by EMO-Space, EPOC will know what emotion he/she is currently in. If the feedback is "Satisfied", then EPOC enters the second stage for advanced calculation. If the emotional state is not "Satisfied", the space will continuously change until EPOC detection is "Satisfied". In the second stage, the relaxation (MED) and stress (FRU) will be analysed. When the subtraction value between the two is greater than 0.5, the user is determined to be "Satisfied". If it is less than 0.5, then EMO-Space will autonomously lower the threshold value. If the threshold value is lowered to less than 0.3, the emotional state will be directly judged as "Satisfied" (Figure 5). In this computational model, EPOC transmits brainwave signals to the computer through Dongle USB for analysis and calculation, reads out the values of 6 psychological states, and transmits them to Python. Python then communicates with Arduino by calculating the user's emotions. These software and hardware provide an interactive bridge with physical spaces.

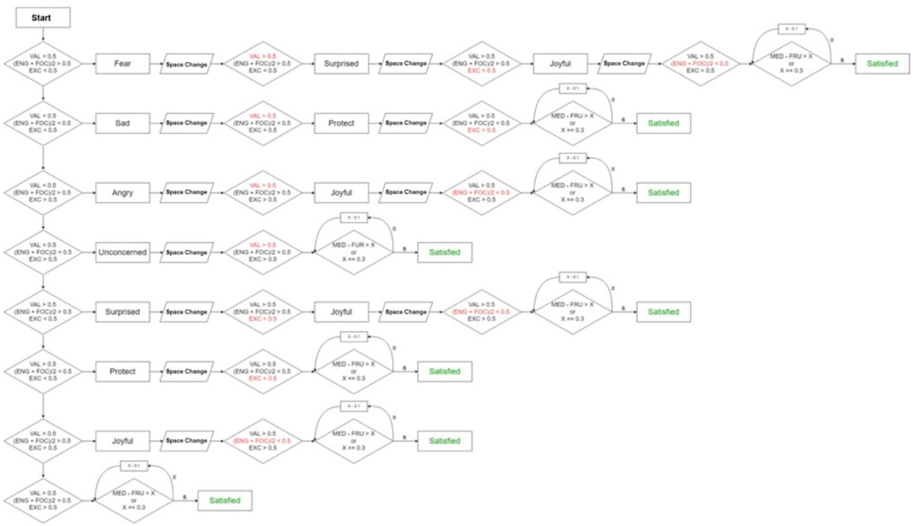

Figure 5. EMO-Space, the computational model implementation

4. Design Experiment

To understand the computational operation of EMO-Space, we conduct a design experiment. In this experiment, we design a dynamic skin called EMO-Skin. Based on our previous study (Lai, et. al, 2022), EMO-Skin can dynamically and autonomously adapt the spatial shapes (including triangle, circle, flower and square) and opening ratios (including 10%, 50%, and 100%) in response to the 8 emotional states of the PAD Model. Through the transformation process from negative emotions to positive emotions, finally EMO-Space reaches the emotional state "Satisfied" and terminates the adaptative change of EMO-Skin.

4.1. EMO-SKIN AND PROTOTYPES

EMO-Skin is composed of four sets of identical prototypes to create spatial changes in shape and opening ratio (Figure 6). The movement of each prototype is independent. When the prototypes receive signals from the computer, they will deform, combine, and form various spaces to respond to different emotional states. For example, the shape triangle and opening ratio 10% respond to the emotional state "Anger". Each prototype includes "shape control component" and "opening ratio control component". The shape control component is composed of a motor and a screw. The opening ratio control component is composed of metal wires and folding plates. All components are fixed in the structural frames of each prototype.

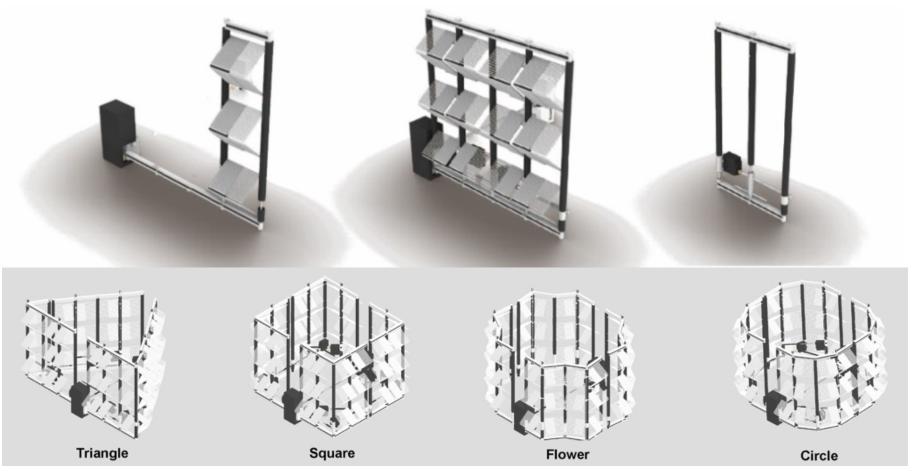

Figure 6. EMO-Skin, prototypes, and their deformations

4.2. TESTING AND SIMULATION

Limited by the fact that there is no real scale 1:1 construction to provide human real experience, we simulate an experiment to test whether the computation mechanism and coding of EMO-Space are correct, and whether the deformation of EMO-Skin responds to appropriate emotional states based on the previous study. In the simulation experiment, we let the subject to watch videos to observe how the generated emotions respond to the deformation of the space. To make the process easier to observe, we selected two sets of videos with obvious emotional changes including "Fear" and "Joyful". Subsequently, the subject wore the EPOC to watch the two videos. To prevent the subject from being affected by the external environment, we set the experimental environment in a quiet space of about 3 or 4 square meters. In the space, the subject can concentrate on the videos he is watching (Figure 7).

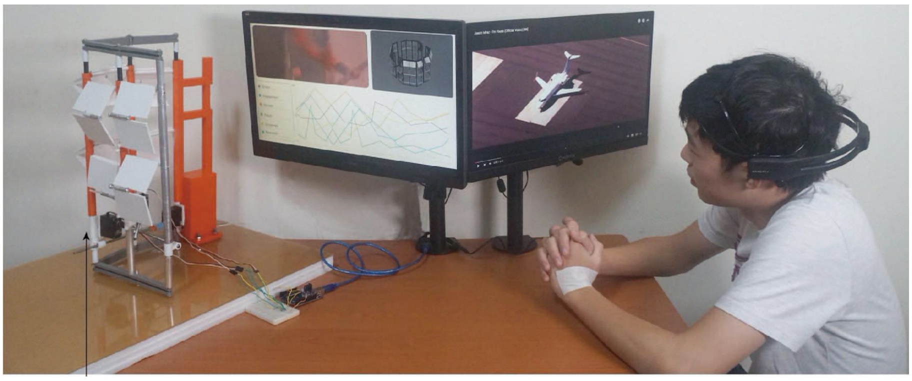

Figure 7. Testing and Simulation

5. An Example: Emotion Sport

In order to further understand the practical application of EMO-Space, we participated in a national design competition. This competition is organized by the Architecture and Building Research Institute, Ministry of the Interior, ROC (Taiwan) for the "Smart Living Space" competition. This competition emphasizes the application of digital technology in architectural space and provides innovative solutions that meet the needs of our future life. In our design work, we believe that exercise can calm negative emotions such as anger, sadness, etc. For example, in an angry emotional state, we can use high-intensity exercises such as boxing and taekwondo to soothe your muscles and calm your emotions. In addition, people's emotions will be affected by the architectural space, and then affect the effectiveness of exercise. Through changing the spatial conditions interactively based on the human emotions, we hope to create a sport venue to achieve the exercise goal of getting twice the result with half the effort (Figure 8).

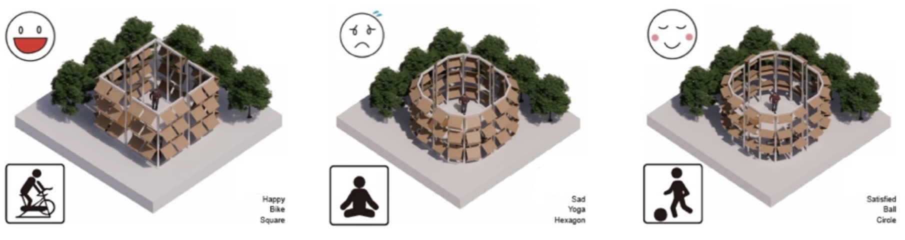

Figure 8. The relationships among exercises, emotions, and spaces

The site is in the Huashan Cultural Center in Taipei. We designed a sports centre called "Emotion Sport" based on the computational mechanism of EMO-Space and the construction of EMO-Skin. According to the user's emotions, the shape and opening ratio of the exercise space will be changed to respond to the most appropriate exercise, and then improve the effects of exercises. Before entering the sports centre, users need to wear EPOC to determine the state of emotion and convert it into data for calculation. The system then recommends the type of exercise that suits the user's current emotion from the database and transforms the space into a suitable shape and opening ratio to satisfy the user's emotion. Finally, this work won the first place in this competition. Its animation will be demonstrated in our final presentation.

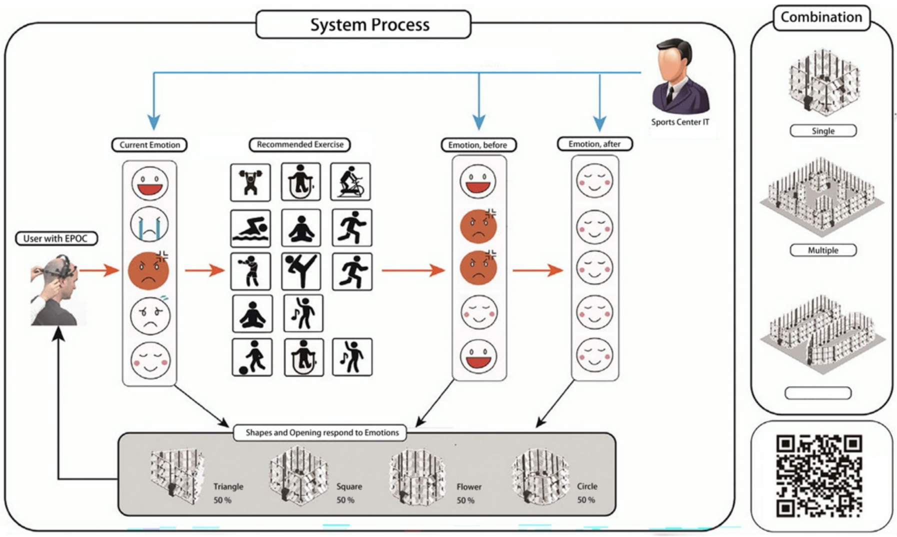

Figure 9. The system process of Emotion Sports

6. Finding and Conclusion

Human brain waves provide us with an understanding of the relationship between emotions and space. This study integrates the PAD model and interactive technology BCI to construct a computational model of emotional space called EMO-Space. EMO-Space can autonomously adapt space according to personal emotional states and satisfy the user in the space finally. The non-invasive EPOC BCI provides a safety way and funding availability to approach the research. Its 6 psychological states can be effectively corresponded to 8 emotional states based on three quadrants in the PAD model. Through this experiment, EMO-Space can map various emotional states to appropriate spatial shapes and opening ratios. The decision tree builds the basis for emotion transformation from negative emotions to positive emotions. The threshold value decides the degree of difficulty to "satisfy" user's emotion, but the value should be different depending on different users. There is a time difference between the two processes of emotional transformation and spatial deformation. This problem requires simplification of the spatial deformation process.

However, the detection of brain waves is highly complex, which affects the accuracy of detecting emotions. To improve accuracy in the future, we can use AI training to design an experimental process, combine more subjects, and collect the values of six psychological states of EPOC corresponding to each emotional states of PAD model. In addition, we can apply Pandas, Numpy and other packages in Python to perform data processing, and then use Pytorch, Tensorflow to implement AI training. The machine learning library can perform the above emotional classification training in a GPU-accelerated environment. While Merleau-Ponty's "Phenomenology of Perception" underscores the significance of the relationships between emotions and perceptions, this research can help us to understand the relationship between spatial elements and emotions, and then to design spatial atmosphere and architectural experience through various types of human perceptions. Facing the future trend of aging, due to the elderly with limited mobility or speech impairment, this research provides a new way of communication between their emotions and living environments, and then helps in their care. In addition, this kind of communication also opens new possibilities for spatial healing.

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