Université de Montréal

Virtual Reality Therapy for Alzheimer's Disease with Speech Instruction and Real-time Neurofeedback System

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Résumé

La maladie d'Alzheimer (MA) est une maladie cérébrale dégénérative qui entraîne une perte progressive de la mémoire, un déclin cognitif et une détérioration graduelle de la capacité d'une personne à faire face à la complexité et à l'exigence des tâches quotidiennes nécessaires pour vivre en autonomie dans notre société actuelle. Les traitements pharmacologiques actuels peuvent ralentir le processus de dégradation attribué à la maladie, mais ces traitements peuvent également provoquer certains effets secondaires indésirables. L'un des traitements non pharmacologiques qui peut soulager efficacement les symptômes est la thérapie assistée par l'animal (T.A.A.). Mais en raison de certaines limitations telles que le prix des animaux et des problèmes d'hygiène, des animaux virtuels sont utilisés dans ce domaine. Cependant, les animaux virtuels animés, la qualité d'image approximative et le mode d'interaction unidirectionnel des animaux qui attendent passivement les instructions de l'utilisateur, peuvent difficilement stimuler le retour émotionnel entre l'utilisateur et les animaux virtuels, ce qui affaiblit considérablement l'effet thérapeutique.

Cette étude vise à explorer l'efficacité de l'utilisation d'animaux virtuels à la place d'animaux vivants et leur impact sur la réduction des émotions négatives chez le patient. Cet objectif a été gardé à l'esprit lors de la conception du projet Zoo Therapy, qui présente un environnement immersif d'animaux virtuels en 3D, où l'impact sur l'émotion du patient est mesuré en temps réel par électroencéphalographie (EEG). Les objets statiques et les animaux virtuels de Zoo Therapy sont tous présentés à l'aide de modèles 3D réels. Les mouvements des animaux, les sons et les systèmes de repérage spécialement développés prennent en charge le comportement interactif simulé des animaux virtuels. De plus, pour que l'expérience d'interaction de l'utilisateur soit plus réelle, Zoo Therapy propose un mécanisme de communication novateur qui met en œuvre une interaction bidirectionnelle homme-machine soutenue par 3 méthodes d'interaction : le menu sur les panneaux, les instructions vocales et le Neurofeedback.

La manière la plus directe d'interagir avec l'environnement de réalité virtuelle (RV) est le menu sur les panneaux, c'est-à-dire une interaction en cliquant sur les boutons des panneaux par le contrôleur de RV. Cependant, il était difficile pour certains utilisateurs ayant la MA d'utiliser le contrôleur de RV. Pour accommoder ceux qui ne sont pas bien adaptés ou compatibles avec le contrôleur de RV, un système d'instructions vocales peut être utilisé comme interface. Ce système a été reçu positivement par les 5 participants qui l'ont essayé.

Même si l'utilisateur choisit de ne pas interagir activement avec l'animal virtuel dans les deux méthodes ci-dessus, le système de Neurofeedback guidera l'animal pour qu'il interagisse activement avec l'utilisateur en fonction des émotions de ce dernier. Le système de Neurofeedback classique utilise un système de règles pour donner des instructions. Les limites de cette méthode sont la rigidité et l'impossibilité de prendre en compte la relation entre les différentes émotions du participant. Pour résoudre ces problèmes, ce mémoire présente une méthode basée sur l'apprentissage par renforcement (AR) qui donne des instructions à différentes personnes en fonction des différentes émotions. Dans l'expérience de simulation des données émotionnelles synthétiques de la MD, la méthode basée sur l'AR est plus sensible aux changements émotionnels que la méthode basée sur les règles et peut apprendre automatiquement des règles potentielles pour maximiser les émotions positives de l'utilisateur.

En raison de l'épidémie de Covid-19, nous n'avons pas été en mesure de mener des expériences à grande échelle. Cependant, un projet de suivi [**33**] a combiné la thérapie de RV Zoo avec la reconnaissance des gestes et a prouvé son efficacité en évaluant les valeurs d'émotion EEG des participants.

Mots clés: Maladie d'Alzheimer, Réalité virtuelle immersive, EEG, Agent intelligent, Environnement immersif, Reconnaissance vocale, Zoothérapie, Émotions, Apprentissage par renforcement, Encodeur automatique, Algorithmes d'optimisation de la politique proximale.

Abstract

Alzheimer's disease (AD) is a degenerative brain disease that causes progressive memory loss, cognitive decline, and gradually impairs one's ability to cope with the complexity and requirement of the daily routine tasks necessary to live in autonomy in our current society. Actual pharmacological treatments can slow down the degradation process attributed to the disease, but such treatments may also cause some undesirable side effects. One of the non-pharmacological treatments that can effectively relieve symptoms is animal-assisted treatment (AAT). But due to some limitations such as animal cost and hygiene issues, virtual animals are used in this field. However, the animated virtual animals, the rough picture quality presentation, and the one-direction interaction mode of animals passively waiting for user's instructions can hardly stimulate the emotional feedback background between the user and the virtual animals, which greatly weakens the therapeutic effect.

This study aims to explore the effectiveness of using virtual animals in place of their living counterpart and their impact on the reduction of negative emotions in the patient. This approach has been implemented in the Zoo Therapy project, which presents an immersive 3D virtual reality animal environment, where the impact on the patient's emotion is measured in real-time by using electroencephalography (EEG). The static objects and virtual animals in Zoo Therapy are all presented using real 3D models. The specially developed animal movements, sounds, and pathfinding systems support the simulated interactive behavior of virtual animals. In addition, for the user's interaction experience to be more real, the innovation of this approach is also in its communication mechanism as it implements a bidirectional human-computer interaction supported by 3 interaction methods: Menu panel, Speech instruction, and Neurofeedback.

The most straightforward way to interact with the VR environment is through Menu panel, i.e., interaction by clicking buttons on panels by the VR controller. However, it was difficult for some AD users to use the VR controller. To accommodate those who are not well suited or compatible with VR controller, a speech instruction system can be used as an interface, which was received positively by the 5 participants who tried it.

Even if the user chooses not to actively interact with the virtual animal in the above two methods, the Neurofeedback system will guide the animal to actively interact with the user according to the user's emotions. The mainstream Neurofeedback system has been using artificial rules to give instructions. The limitation of this method is inflexibility and cannot take into account the relationship between the various emotions of the participant. To solve these problems, this thesis presents a reinforcement learning (RL)-based method that gives instructions to different people based on the multiple emotions accordingly. In the synthetic AD emotional data simulation experiment, the RL-based method is more sensitive to emotional changes than the rule-based method and can automatically learn potential rules to maximize the user's positive emotions.

Due to the Covid-19 epidemic, we were unable to conduct large-scale experiments. However, a follow-up project [**33**] combined the VR Zoo Therapy with gesture recognition and proved the effectiveness by evaluating participant's EEG emotion values.

Keywords: Alzheimer's Disease, Immersive Virtual Reality, EEG, Intelligent Agent, Immersive Environment, Speech Recognition, Zoo Therapy, Emotions, Reinforcement Learning, Auto encoder, Proximal Policy Optimization Algorithms.

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List of acronyms and abbreviations

AD	Alzheimer's Disease
MCI	Mild Cognitive Impairment
CST	Cognitive Stimulation Therapy
AAT	Animal-Assisted Therapy
VR	Virtual Reality
EEG	Electroencephalography
NavMesh	Navigation Mesh
BFS	Breadth-First Search
2D	2 Dimensions
3D	3 Dimensions
HCI	Human-Computer Interaction

ASR	Automatic Speech Recognition
RL	Reinforcement Learning
FFT	Fast Fourier Transform
Hz	Hertz

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Chapter 1

Introduction

1.1. Overview

1.1.1. Introduction to Alzheimer's disease (AD)

Alzheimer's disease (AD) is a slowly developing and degenerative brain disease, meaning that it will become more and more severe over time. According to the latest data from the World Health Organization in 2021 [**45**], it is the most common form of dementia and may contribute to 60–70% of cases.

AD will affect cognitive ability, behavioral ability, language ability, and mental health. Its most notable symptom is the decline in memory, such as repetitive questions or conversations, getting lost on a familiar route. Other symptoms include some apathy and depression, impairment in communication, confusion, ultimately difficulty speaking, swallowing, and walking. The severity of symptoms will increase over time and progress from a single symptom to multiple symptoms coexisting. Eventually, the patient will completely miss the ability to work and daily activities.

The cause of AD is poorly understood. According to the Alzheimer's association report: «2020 Alzheimer's disease facts and figures» [**48**], the three greatest risk factors for Alzheimer's are older age, genetics, and having a family history of Alzheimer's. Age is the greatest risk factor for this disease. The vast majority of people who develop AD are age 65 or older. As the age increases, the proportion of AD in the elderly also increases.

Before these patients die, they live through several years of morbidity as the disease progresses. The report: «2020 Alzheimer's disease facts and figures» [**48**] shows people age 65 and older survive an average of 4 to 8 years after a diagnosis of Alzheimer's dementia, yet some live as long as 20 years with Alzheimer's dementia . In an analysis « Letha-lity of alzheimer disease and its impact on nursing home placem» [**4**] report, patients from age 70 to age 80 will spend an average of 40% of their time in the severe stage in a nursing home. That signifies that these elders will spend most of their time in a state of disability and dependence. Daily life can only depend on family or nursing center. This is extremely heavy for patients and their families and also, a burden on the society and the economy because the cost of this care is long and uninterrupted. Costs of this care are involving pharmaceuticals, nursing home care, in-home daycare, lost productivity of both patient and caregiver. Some reports and studies [**27, 32, 10, 41**] show that AD may be one of the costliest diseases in European and American society.

According to data from the World Health Organization [**45**] and « The cost of alzheimer's disease in china and reestimation of costs world » [**29**], in 2015, the total global societal cost of dementia was estimated to be US $ 818 billion, equivalent to 1.1% of global gross domestic product (GDP). The global socioeconomic costs for dementia will reach US $ 2.54 trillion by 2030, and US $ 9.12 trillion by 2050 . Based on the World Health Organization, worldwide around 50 million people have dementia, and there are nearly 10 million new cases every year. The total number of people with dementia is projected to reach 82 million in 2030 and 152 million in 2050 [**45**]. With the growth of the aging population, that cost-share in the globe GDP will grow even larger.

Under this growth trend, any treatment that can stop or slow cognitive decline, or delay institutional care, or reduces the duration of care will be very beneficial to patients, family members, and society. Regrettably, no treatments today stop or reverse AD's progression, though some may improve symptoms. Researchers of the Alzheimer's association [**48**] believe that future treatments to slow or stop the progression of AD and preserve brain function may be the most effective when administered early in the disease.

1.1.1.1. Stages of AD

In a study by Victor L.Villemagne and Samantha Burnham [**57**] called «Amyloid β deposition, neurodegeneration, and cognitive decline in sporadic Alzheimer's disease: a prospective cohort study», they found that AD should have started many years before the symptoms appeared. It is just that the brain changes are unnoticeable to the patient. After years of brain changes, the individual will have noticeable symptoms, such as memory loss and language barriers. These symptoms appear because nerve cells (neurons) in the brain involved in thinking, learning, and memory (cognitive functions) are damaged or destroyed. As the disease progresses, neurons in other parts of the brain will also be damaged or destroyed. When brain nerve cells with different functions are damaged, more symptoms will gradually appear. Eventually, those nerve cells that perform physical functions, such as walking and swallowing, are also damaged. Patients will not be able to take care of themselves and need 24 hours of care. This disease is ultimately fatal. In 2019, «The top 10 causes of death worldwide» [**45**] published by the World Health Organization, AD and other forms of dementia ranked as the seventh leading cause of death worldwide .

AD's progression starts from unnoticeable brain changes to memory problems to physical disability until death. By 2020 Alzheimer's Association report [**48**], this progression can be divided into three broad stages:

(1) Preclinical Alzheimer's disease: At this stage, the nerve cells in the brain have changed, the patient's cognitive ability has a slight change, but there are no AD symptoms.

(2) Mild cognitive impairment (MCI) due to Alzheimer's disease: At this stage, the patient's most common symptom is a cognitive dysfunction, such as memory loss, difficulty communicating, and mood changes.

(3) Dementia due to Alzheimer's disease: This phase is broken down again into the stages of mild, moderate, and severe, which reflect the degree to which symptoms interfere with the patient's ability to carry out everyday activities.

    At this stage, the cognitive and behavioral abilities will decline more than the MCI stage, and multiple symptoms coexist, like communication disturbances, confusion, poor judgment, and behavior changes, which eventually lead to difficulty speaking, swallowing, and walking. At the moderate and severe stages, the patient's physical functions will be lost and require full-time care until death.

We found that in the progression of AD, when the gradual deterioration of cognitive function appears, emotional changes also follow the entire process. According to «The diagnosis of dementia due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease» [**40**], when entering the third stage (dementia due to Alzheimer's disease), the personality, behavior, and comportment will change a lot, symptoms include uncharacteristic mood fluctuations such as agitation, anxiety, depression, impaired motivation, apathy, loss of drive, social withdrawal, decreased interest in previous activities, loss of empathy, compulsive or obsessive behaviors, socially unacceptable behaviors.

Such emotional fluctuations, with negative emotions, can cause distress to AD patients, their relatives and friends, and even medical staff. This leads to more negative emotions, a vicious circle. Negative emotions are not only symptoms of AD, but also the cause and accelerator of the disease.

1.1.1.2. Impact of negative emotions for AD

With the development of the disease, the neurons in the brain area involved in emotions become more and more damaged, which will lead to more negative emotions like agitation, anxiety, depression. So will negative emotions affect the process of AD in turn? The answer is yes. Negative emotions such as depression and stress can cause a series of changes in the brain and impair cognitive and memory functions.

Depression is highly prevalent in mild cognitive impairment and most dementia such as AD. A review [**47**] thinks that depression may be a risk factor for the subsequent development of dementia and in some conditions may be a prodromal symptom, or even the cause. A study [**54**] shows elderly with depression show more impairment in memory, visual space, and executive function than those without depression

Study [**42**] by D.B.Miller «Aging, stress and the hippocampus» have shown that under stress, the body releases a hormone (called glucocorticoids) that can destroy neurons in the memory function area of the brain. The longer the pressure exposure, the greater its impact. However, short-term stress can also cause memory impairment.

Although negative emotions are not the direct cause of AD, they can increase the risk of disease and accelerate the progression of AD. Among the many treatments for AD, recent studies such as « Adaptive music therapy for Alzheimer's disease using virtual reality » [**13**] by Alexie Byrns, «Application of Virtual Travel for Alzheimer's Disease » [**1**] by Hamdi Ben Abdessalem and Alexie Byrns,and «Virtual savannah: An effective therapeutic and relaxing treatment for people with subjective cognitive decline » [**18**] by Caroline Dakoure have shown that reducing depression, stress and other negative emotions has a clear outcome to improve the memory functions and cognitive abilities.

1.1.2. Treatment of AD

Current treatments are divided into pharmacological treatment (medications) and non-pharmacological therapy. But there is currently no cure for the disease.

Medical research has developed medications to help reduce the severity of disease symptoms, such as depression, stress, and anxiety thereby delays the progress of the disease. Although these medications are helpful, they cannot stop or reverse the progress of the disease and sometimes produce undesirable side effects. Fortunately, non-pharmacological treatments, such as music, animal, and virtual reality treatments, have shown positive results in eliminating negative emotions and improving cognitive function. It can be used in a larger population without side effects.

1.1.2.1. Pharmacological

Pharmacological treatment is the treatment of the patient by giving medications. Medications used to treat the cognitive problems of AD include acetylcholinesterase inhibitors and memantine. «Pharmacological treatment of Alzheimer disease» [**14**] mentions clinical trials have shown statistically significant benefits with those medications on cognitive, emotional, functional, and behavioral outcome measures. But these benefits are modest, and none of these medications has shown consistent benefits. They do not alter disease course as indicated in [**48**] and sometimes there are many side effects.

Acetylcholinesterase inhibitors may have side effects (such as nausea, vomiting, even muscle cramps, decreased heart rate). Brian K. Alldredge mentioned in his book «Applied therapeutics: the clinical use of drug» [**2**], these side effects can be managed by slowly adjusting medication doses. However, the reduction in dosage may affect the treatment effect of AD. The side effects of memantine are hallucinations, confusion, headache, dizziness [**46**]. It is necessary to use antipsychotics to reduce these side effects. However, such antipsychotics can also cause more serious side effects, such as stroke, movement difficulties, or cognitive decline [**7**]. Clive Ballard in «The dementia antipsychotic withdrawal trial (DART-AD): long-term follow-up of a randomised placebo-controlled trial» [**6**] showed that long-term use of this antipsychotic in AD patients increases the risk of mortality. In this case, we understand that non-pharmacological therapy is more researched and developed.

1.1.2.2. Non-pharmacological

Non-pharmacological therapies are those that do not involve medication. They are used for people with AD to maintain or improve cognitive function, quality of life, or the ability to complete activities of daily living. They also may be used to reduce emotional or behavioral symptoms such as depression, apathy, wandering, sleep disturbances, agitation, and aggression [**48**].

Determining the effectiveness of non-pharmacological treatments may be difficult because of the diversity of treatment goals (from improving the overall quality of life to improving specific symptoms), or the diversity of treatment items (therapist, treating animals, computers, VR games). In the « 2020 Alzheimer's disease facts and figures » [**48**] published by the AD Association, researchers have pooled data from multiple studies of non-pharmacological therapies to provide insight into their potential effectiveness. Finally, many systematic reviews [**34, 5, 63**] reported that some cognitive stimulation therapies are effective for neuropsychiatric emotional symptoms, such as depression, apathy, and anxiety, thus improving the quality of life of AD patients.

Cognitive stimulation therapy is a kind of stimulation-oriented treatment, which supports improving behavior, mood, and cognitive function through external stimulation of the brain. It includes art, music and animal, exercise therapies, and recreational activities (like VR treatment). Among them, VR, music, and animal-assisted therapy have shown positive effects in applications.

1.1.2.3. Virtual Reality (VR) for AD

VR is a 3D virtual world created by computer simulation, where users can look around the artificial world, move around in it, and interact with virtual items in real-time. Modern virtual reality headsets use gyroscopes and motion sensors for tracking users' head, body, and hand positions in the real world and integrated that information into the virtual world that people see to simulate a user's physical presence in a virtual environment. Therefore, although what you see is a virtually built environment, all the reactions in it will be the same as in the real world. Hence, the reality of the simulated environment is indistinguishable from the real world. It gives the user a sense of being there and immersion in this world.

Over the last couple of decades, VR technology has been applied in various fields and has achieved notable results in the psychological field. Indeed, VR has been used to treat various diseases, including brain damage [**49**], anxiety disorders and reduce fear [**24**]. In addition, VR has also been shown to help restore cognitive function.

For example, some studies [**3, 8**] focus on the use of VR to help users improve cognitive performances. Some research such as «Computerized and Virtual Reality Cognitive Training for Individuals at High Risk of Cognitive Decline» [**16**] by Hannah Coyle B.Psych, «Computerized Cognitive Training in Older Adults With Mild Cognitive Impairment or Dementia» [**26**] by Nicole T.M.Hill, and «Outcomes associated with virtual reality in psychological interventions: where are we now?» [**55**] by Wesley A.Turner showed that VR intervention with computerized cognitive training can improve cognitive functions in individuals with mild cognitive impairment or AD.

VR can get users' more active participation, and the more engaging training will be more effective. The experiment «A Feasibility Study with Image-Based Rendered Virtual Reality in Patients with Mild Cognitive Impairment and Dementia» [**35**] by Valeria Manera observed that AD patients find it more engaging and prefer performing cognitive training tasks in VR over its pencil-paper counterpart. Interestingly, apathetic participants showed a preference for the VR condition stronger than that of non-apathetic participants. This provides conditions for AD patients to cooperate with VR treatment, and some recent VR therapies combined with traditional therapies have also shown positive effects for AD.

In a study [**13**] called «Adaptive Music Therapy for Alzheimer's Disease Using Virtual Reality» by Alexie Byrns, VR technology integrated traditional music therapy. This therapy designed a virtual reality music theater in which participants are immersed among the audience and enjoy music, accompanied by light and shadow visual effects. The study screened 19 AD patients for the experiment, with an average age of 72 years. The researchers observed and analyzed the changes in patients' attention, memory, positive and negative emotions before and after using the VR music theater. The result indicates that this VR music therapy not only reduces the negative emotions but also improves the memory of most users.

Another experiment «Application of Virtual Travel for Alzheimer's Disease» [**1**] by Hamdi Ben Abdessalem also combines VR technology with traditional travel therapy. The experimenter believes that VR travel can mobilize participants' attention and revive their interest and curiosity. Because their VR environment can isolate participants from external factors that may induce negative emotions. The 19 participants put on VR headsets and found themselves in a train. They can see the situation in the carriage and the scenery outside the window. The experience result shows that this VR travel therapy also reduces negative emotions to a certain extent and improves the cognitive and memory ability of participants.

These experiments show that VR technology provides development and continuation of traditional effective treatments. It is feasible and effective to superimpose VR technology on music therapy, and travel therapy. That provides more possibilities for other traditional therapies.

1.1.3. Animal-assisted therapy (AAT) for AD

Animal-assisted therapy (AAT) is an interaction between humans and animals for therapeutic purposes. It's performed by a professional team with the involvement of specifically selected real animals for different purposes of treatments. The most common animals used for therapy are dogs and horses. They provide comfort, cheer, companionship and help someone recover from a health problem or mental disorder. Spending time with calm and cheerful animals improves patients' social, emotional, and cognitive functions [**50**].

1.1.3.1. Evidence from AAT

The effectiveness of AAT has been proven and can be accepted by most patients. It can satisfy some fundamental human needs such as attention and feelings of affection. «The Science Behind Animal-Assisted Therapy» [**36**] aims to study whether AAT can help relieve pain. The results show that visits by treatment dogs are beneficial to reduced pain and pain-related symptoms. It shows that benefits from therapy dog visits exceed those from spending time with a friendly volunteer. And during the treatment dog visit, the patient's mood remained stable and more willing to treat. People were also more likely to feel attached to the dog than the human volunteer. Another study [**53**] aimes to verify the effectiveness of AAT in improving the well-being of the elderly living in a nursing home. The researchers measured anxiety, depression, apathy, loneliness, and quality of life in the elderly before and after the intervention. The result confirmed that the measured variables were improved significantly. That is to say, the implementation of AAT can have a **positive impact on the negative emotions** and quality of life of the elderly.

For AD, AAT is a simulation-oriented treatment in non-pharmacological treatment. Patients with dementia such as AD are usually more apathetic and frustrated than the others elderly. Can AAT also achieve good results for them?

To evaluate the impact of AAT on AD, the study «Effects of animal-assisted therapy (AAT) carried out with dogs on the evolution of mild cognitive impairment» [**11**] conducted an experiment on 24 AD MCI patients and randomly divided them into two groups: AAT treatment group and control group both followed for eight months. And researcher compared the changes in their cognitive abilities, depression status, and their daily life status. The results show that the AAT treatment group can reduce or pause the decline of the patients' daily living ability and cognitive ability, the progress of AD is slow, and there is no depressive syndrome.

AAT is not only effective for mild patients but also moderate and severe patients. The «Effects of an animal-assisted intervention on social behavior, emotions, and behavioral and psychological symptoms in nursing home residents with dementia» [**59**] has a similar experiment process, but the experiment subjects are moderate to severe dementia patients, followed for 6 months. The results also showed the improvement of AAT on social behavior, mental state, emotion, and social interaction ability.

There are many other experiments [**43, 44, 22, 50**] that have verified the positive effects of AAT on dementia and AD. The subjects of these experiments cover all stages of dementia and AD patients from mild (MCI) to severe. It shows that AAT can improve cognitive functions (such as memory, space-time positioning, calculation and organization skills, and language), psychological symptoms, emotions, social interactions skills, and quality of life. Through these results, we can affirm the potential of AAT as a non-pharmacological therapy in the treatment of deficits deriving from Alzheimer's disease patients.

AAT has different sizes of treated animals. Small animals that will be used include cats, dogs, rabbits, and even pigs. Large animals are horses or dolphins. Among them, dogs are the most commonly used in small animals and show the most significant treatment effects, while large animals are horses. Barbara W. McCabe, author of «Resident Dog in the Alzheimer's Special Care Unit» [**39**] believes that dog therapy had a "calming effect" on patients with dementia and Alzheimer's disease. People with Alzheimer's may have an easier time decoding the simple repetitive, non-verbal actions of dogs. Animals can act as transitional objects, allowing people to first establish a bond with them and then extend this bond to people. Horse therapy shows that after treatment, people's psychological distress is reduced and mental health is improved significantly, and the effect is sustainable which mentions in«The Effectiveness of Equine-Assisted Experiential Therapy: Results of an Open Clinical Trial» [**9**]. Trained horses can give accurate and unbiased feedback to elicit a range of emotions and behaviors in humans. According to «Animal assisted therapy and activities in Alzheimer Disease» [**15**] by Sibel Cevizci, the interaction between an animal and human results in an increased neurochemical initiating a decrease in blood pressure and relaxation. This may be beneficial for soothing agitate behavior and psychological symptoms of dementia.

Although the effect of animal therapy is good, it does have certain limitations.

1.1.3.2. Limitations of AAT

Three reasons may cause AAT does not use on a large scale as a non-pharmacological treatment: the first reason is maintenance, the second is cost, and the third is ethical concerns.

– Generally, **maintaining** AAT requires a team of animal therapists, veterinarians, and treated animals. This treatment animal is different from pets. The quality of the animal directly affects the treatment effect. So it will be screened layer by layer according to treatment purposes. The animal evaluation team makes professional evaluations of the animal's physical performance, personality characteristics, understanding ability, safety factor, etc [**50**]. The animals that pass the evaluation also need to do a series of training to adapt to the treatment. And they not only need to receive vaccines, physical examinations, and reassessments on time, for each treatment, disinfectant wipes were used to clean the animal to avoid the transmission of zoonotic agents (e.g., bacteria, fungi, parasitic elements) which mentions in « Animal-Assisted Therapy as a Non-Pharmacological Approach in Alzheimer's Disease: A Retrospective Study » [**51**]. Even if the treatment animal is perfect, an animal does not always play a role perfect on the user in every treatment, so not every treatment can achieve the desired effect.

– In terms of **cost**, the cost of the animal's feeding, training, inspection, activity space, transportation, and human will increase as the size of the animal increases. Besides, there are the evaluation costs of treatment animals, the cost of regular physical examinations, and the cost of accompanying veterinarians during treatment, etc. If animals are rented, in addition to rental and transportation costs, untrained animals may increase the treatment risk or reduce the treatment effect.

– For **ethical reasons**, despite AAT has benefits for humans, but it harms the mental and physical well-being of the animals. Two unsystematic narrative review [**23, 20**] respectively present the current status of treatment dogs and treatment horses in AAT. It mentions the psychological pressure brought by the behavioral control of the animals when they are used for treatment. The negative emotions generated not just affect the animal but also harm the patient. And not only physical constraints can cause psychological stress on animals, these reports even include mistreating and teasing the dogs by patients and staff [**23**]. Certain disabilities had to be excluded from the experiment due to an increase in the stress of the therapy dog, and a decline in overall well-being [**23**].

When AAT uses real animals, these limitations might be inevitable, so is it possible to avoid these limitations by integrating traditional AAT with new techniques, like the VR music therapy mentioned in the previous section? A solution would be to use technology to virtualize animals, but retain the interaction between patients and animals to achieve the therapeutic effect of AAT.

1.1.3.3. Virtual AAT

Although AAT is a well-known effective therapy, there are not many virtual AATs for treatment, especially for AD.

A VR treatment: «Virtual Savannah: An Effective Therapeutic and Relaxing Treatment for People with Subjective Cognitive Decline» [**18**] is a treatment involving virtual animals. When users wear VR headsets, they will find themselves in a prairie, where they can see the running antelope, the elephant bathing, and the eagle flying in the sky. Participants can relax through virtual environments and animals. The results show that 10 minutes of experience in this virtual savannah can reduce the negative emotion (like frustration) of most AD patients. This experiment mainly relies on watching savannah and animals to relax and patients do not interact with those virtual animals. However, in AAT, the patient gets cognitive stimulation and the attachment to the animal from the interaction with the animal. So,for the AAT of a virtual animal, it's not enough to watch without interacting with virtual animals.

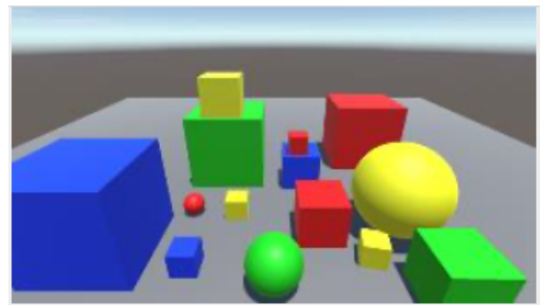
Another AAT uses virtual animal interaction for AD treatment named «Animal-Assisted Therapy for Alzheimer Patients Using Virtual Reality» [**21**] by Henrique Dantas Ferreira. This project hopes to develop a virtual animal interactive **game** for AD patients to perform common activities done during the real animal therapy process. In this way, it can explore and verify that virtual animal therapy is feasible, and the extent to which it can capture the most positive aspects of AAT without having the shortcomings of real animal therapy. Since there has been no similar attempt before, the project first conducted a pilot study on which technologies and interaction methods were preferred for AD patients, those with advanced age and cognitive impairment. Then they use the selected interactive method to develop interactive games. Next, let us present some important parts of this experiment (interaction method select, game design, and result).

First of all, the most important point to interact with virtual animals is the way of interaction. Unlike real animals, virtual animals are not within reach. They are in computers and other devices. Some hardware devices are bound to interact with virtual animals as intermediaries like a mouse or controller. The interactive method of this game needs special selection because this game's target population is AD patients. As we have already introduced, the typical symptoms of AD patients include cognitive impairment, behavioral ability decline, and visual impairment. Then they may have some difficulties when using the device to interact with the virtual animal. For example, cognitive impairment may cause them to fail to understand the use of the device. Behavior and visual ability will affect the use. Therefore, the project designed a series of small games and a combination of different interactive devices to find out the user's favorite and best interaction method.

The experiment from Ferreira selected five technologies from many technologies: HTC VIVE (VR), PC (with the mouse), Tablet, AR (using projections), and the Leap Motion Controller. The experiment not only tested the use of a certain technology alone but also tested some technology combinations, such as HTC VIVE with Leap Motion. To test whether users can use these technologies, the researchers designed some small games, which include moving objects to designated locations, grabbing virtual objects, observing the virtual environment, playing musical instruments, etc. As shown in the Figure 1.1, participants need to choose different technologies to complete these games and tell the researchers about the experience and problems at any time.

The study has 12 participants. They were asked to use different technologies for a 15-minute experience, and they could experience 10 tasks in total. They can ask the researchers questions or stop the experience at any time during the process. Among them, 6 participants experienced all 10 tasks. The results show that among the 5 technologies, participants prefer direct interaction methods, such as projection, AR, and Tablet. The interactive method with a controller makes some participants feel too complicated such as HTC VIVE (with controller) and computer (with the mouse) [**21**]. Most of the time, they cannot understand how to use the buttons in the controller or how to cooperate. Even after the researchers explained it many times, some participants still couldn't understand how

(a) The player must move the block within the playable area and catch all the red balls before moving to the black block.



(b) The player had to grab and move around virtual objects (spheres, cubes and cylinders)[**21**].

(c) The player had to explore the virtual environment of a Forest and describe what they were seeing (flowers, trees, grass, the sky, etc.)[**21**].

(d) Play a virtual piano

Fig. 1.1. Small games for test 5 technologies,image come from [**21**]

to move the mouse pointer. At the end, the project team chose to use the **Tablet** as an interactive method to develop interactive games out of cost considerations from the three favorite technologies of users.

Next, the researchers designed and developed an interactive **game for Tablets** and Smartphones. Players can perform daily activities in traditional AAT with virtual dogs in the game, such as throwing balls, petting, grooming, and feeding animals. There are 12 different species, and each species has three sizes (small, medium, and large) of 3D model dogs, and four scenes (garden, house, beach, and city) can be chosen, shown as Figure 1.2. Moreover, the game has two modes: Free mode and Grow-A-Dog mode. Free mode is to collect points by continuously satisfying the needs of dogs. Grow-A-Dog mode is to meet the needs of dogs to allow dogs to grow up.

The principle of interaction in this game is to create a Finite State Machine (FSM) that is commonly used decision-making technology in the game. It consists of finite states and

(a) Dogs in this game

(b) Scene selection screen [**21**].

Fig. 1.2. Dogs and Scene selection screen in the game(images from [**21**])

the relationship between states. Each state is an action or behavior, and the relationship between the states indicates whether the two relationships can be a transition to each other and the transition conditions. For example, whether the dog can go from the idle state to the eating state, if it can, there will be certain transition conditions such as time, user instructions, and so on. For the user, on the user interface, the player can complete the interaction of throwing the ball, dropping food, grooming dog, and petting dog by selecting the corresponding object on the action menu (Figure 1.3).

The game was tested on 10 AD patients. 8 of the participants liked dogs, 1participant didn't like dogs, and 1 participant didn't know. Before the intervention, the participants had to conduct **self-emotional evaluation**, and a therapist would also give an emotional evaluation of the participants. After the intervention, participants will conduct a self-assessment again and answer some game experience questions. The therapist will again evaluate the patient's emotions and gives subjective opinions on the impact of the game on the participant. The result of the experiment shown although statistically, it was not possible to determine whether there were any mood changes in the participant after one

Fig. 1.3. The brown box at the bottom of the interface is the action menu.Represents throw the ball, drop some food in the food bowl, groom the animal, pet it respectively.(images from [**21**])

session, therapists observed and reported positive reaction [**21**]. Most of the participants found it interesting during the intervention. Some participants even thought of their pet dogs. One participant thought that virtual dogs were better than real dogs. When asked to what extent the virtual dogs in the game resemble real dogs, most participants said that although the virtual dogs are cute, they are still far away from the real dogs. Two participants **did not even recognize** that these animals are dogs.

This game is a typical animal interactive game currently on the market. Contains some interactive actions between players and virtual animals. The game consciously chooses the touch-based interaction method for AD patients. It realizes the interaction with the dog by clicking on the action options on the screen. Some confusion caused by AD users who touch the Tablet multiple times or in a large area, the developer has added a setting that prohibits multi-point triggering in the game.

Although participants generally have a high degree of acceptance of virtual animals, it is still possible to improve and explore to make virtual AAT display the therapeutic effects of real AAT. We can see some shortcomings from the virtual AAT.

1.1.3.4. Limitations of Ferreira's virtual AAT

As a virtual dog game for AD users, the Ferreira's game is very successful in making participants feel happy. But there are some differences between it and the real AAT, mainly in the following four aspects:

(1) Appearance: The picture quality is **poor**. The cartoonization of virtual animals and virtual environments gives participants a serious sense of unreality (see Figure 1.3).

(2) Game experience: The animal's performance is **rigid**. Animals will perform actions under the rules written in advance, or wait for participant interaction requests. During the game, even if the user's mood does not improve, they can only wait for the end of the game or exit early.

(3) **Interaction** mode: The essential difference from real animals is that the interaction with virtual animals in the game is to transmit interactive information through the intermediary of hardware devices. In other words, participants can connect to the virtual animal by the program by **clicking** on the option on the Tablet to generate **interaction** which is biased, participants can directly interact with animals.

(4) Evaluation method: **lack of objectivity**. The evaluation method of projects like Ferreira is mainly based on the subjectivity of users and therapist. The evaluation standards are not uniform. The result depends on the experience of each therapist. And **self-evaluation** of people with AD cognitive impairment may be inaccurate.

1.2. Research motivations

Alzheimer's disease has affected tens of millions of people worldwide, and the number of patients is still increasing every year. Public resources are consumed and families with patients also have financial and psychological pressure. We can imagine that when we face an elder who accompanies us to growing up or a friend who has been with us for many years, suddenly does not know us, it will be painful for anyone. One day, people who love home can't find their way home, who love to read open the book but don't know the words inside, or who like sports but can't control the body. The loneliness, confusion, helplessness, and even anger and lack of dignity brought about by this can make the patient very painful. The typical characteristics of Alzheimer's disease include **emotional agitation, anxiety, irritability, depression**, and social withdrawal, which are caused by brain nerve damage of the disease. And the various situations that the patient faces will bring more negative emotions. These **negative emotions** will in turn affect and destroy the cognitive function area of the patient's brain and push the further deterioration of the disease.

Due to the side effects of pharmacological treatment, non-pharmacological therapy has attracted attention. Among them, animal-assisted therapy (AAT) that uses animals as the treatment medium is different from therapies such as objects, music, and sports. Animals are living organisms. They have emotions, can perceive human behavior and emotions, and can interact with people. This is also the most important point of this treatment. **This human-animal interaction constitutes a strong emotional background.** It has been reported that resulting benefits would depend on the strength of the emotional interactions [**15**]. In another word, confident, positive, and sedative bonding between a human and an animal can trigger beneficial mechanisms by affecting the secretion of adrenaline and other corticosteroid hormones or stress hormones. The interaction can decrease arterial blood pressure cardiac and respiratory rates. Emotional, psychological impulse, playing, and physical mechanisms used in AAT cause psychosomatic effects [**15**]. Non-organisms cannot give this kind of emotional feedback.

The various limitations of AAT prevent this therapy from being widely promoted. Although some people have tried to use virtual animals to complete AAT, there are still many shortcomings, especially how to perform the most important interactive part of AAT. Existing virtual animal treatments all use cartoon animals, and their interaction is done by clicking on the interactive patterns on the user interface. It is not a direct interaction between the user and the animal. It is more like that a user interacts with a computer, rather than an animal. And these virtual animals cannot give emotional feedback because it can not perceive users. The connection between participants and virtual animals is in one-direction. All the emotional changes of the participants do not affect the actions and behaviors of the virtual animals.

Based on the fact that VR can reduce anxiety, that AAT is a way to reduce also negative emotions our goal is to develop a virtual reality animal-assisted therapy called Zoo Therapy which is able to provide direct interaction with the animal (using voice), stimulate positive emotional feedback in the interaction with the virtual animals, and reduce the user's negative emotions.

We use **Electroencephalography** (EEG) recognition to detect positive and negative emotional responses in the brain. From the beginning of the intervention to the end, the monitoring is uninterrupted. EEG measures real-time changes in voltage caused by brain activity. This measurement method provides the basis and possibility for us to intervene in user emotions in real-time. In other words, EEG can give an evaluation of emotions every frame throughout the game. We take advantage of this feature to specially create a Neurofeedback system. When the system finds that the user's negative emotions are increasing, it will give **direct feedback** and intervention to the user through the behavior change of the virtual animal which is a **dynamic aspect**. In this form, virtual animals are endowed with perception similar to real animals and the ability to actively cooperate with the treatment.

To make the participant's **interaction** with the virtual animal more intuitive, Zoo Therapy added a **speech instruction system** to provide the participant's direct interaction with the animal.

To make animals more real, Zoo Therapy uses **3D models** of real animals and scenes, and they have established a set of specialized actions, sounds, and behavior systems. We use a 360 degrees immersive VR technology able to provide experience like real AAT without their limitations.

1.3. Objective

The focus of our work revolves around obtaining answers for the following research questions.

(1) Is it possible to create an interactive VR environment able to change according to the EEG reactions of the patient?

(2) Is it possible to reduce the negative emotions of the patient using Zoo Therapy?

(3) Is it possible to acquire new rules of interaction with the patient through Neurofeedback approach?

1.4. Thesis architecture

This thesis will discuss in detail how to design, create, and implement Zoo Therapy. The principles, the structures and the training results of the models involved in implementing the interactions. And how it fits into the treatment environment, the algorithms used, and the end result.

The current chapter, Chapter 1, serves as an introduction to this thesis where we discussed the motivation and general principles behind this research.

Chapter 2 discusses the development details of the Zoo Therapy environment.

Chapter 3 presents two methods of interactive system using in Zoo Therapy. **The speech instruction system** and **Neurofeedback system**. We introduce the speech instruction system's model architecture, data recording, training results and the details of how to integrate it with Zoo Therapy and pilot usability tests. In the Neurofeedback system, we will introduce the rule-based method and its limitation. An improved method for rule-based, a Neurofeedback system based on reinforcement learning algorithms will also be introduced. We will explain the structure of this algorithm model, data generation, and results.

Chapter 4 introduces the experimental part, which includes the purpose of the experiment, the participants, the equipment used, the process and results.

Chapter 5 includes conclusion and future Work.

Chapter 2

Development of Zoo Therapy

2.1. The concept

Zoo Therapy's goal is to stimulate positive emotional feedback in the interaction with the virtual animals, reduce the user's negative emotions, and help AD treatment. The more realistic virtual animals are, the easier it is to generate emotional feedback. Therefore, we create a relatively realistic treatment environment and animals for the participants in terms of vision, hearing, and interaction. We have known from Chapter 1 that the most recent virtual animal therapy from Ferreira for therapeutic purposes is generally an interactive game involving animated animals. The picture of the game is rough, the animal behavior pattern is rigid, and the interaction method is single. During the user experience, they are clear that this is a game, which is fundamentally different from the real AAT.

Therefore, Zoo Therapy will provide as far as possible a feeling of interacting with real animals from the treatment environment, animal appearance, sound, animation, behavior, and interaction methods.

In terms of **visual** effects, the static objects in the virtual environment will be all 3D models of high definition, such as sofas, French windows, and even cake forks on the table. The reflection of light on the surface of the object is also like the real world. We will use horses and dogs that are highly accepted in traditional AAT as virtual therapeutic animals. The 3D animal model is like the animal, the changes in muscles even can be seen when the animal moves.

In terms of **auditory** effects, soothing piano music is added to the virtual environment as background music. Each behavior of the virtual animal is also equipped with sound effects, such as walking, running, gasping, barking, etc.

In terms of **sensation**, Zoo therapy establishes a behavior system for virtual animals to support the movement, pathfinding, and interaction. The movement of such animals is unpredictable. In addition, we use three different interaction methods, traditional human-computer interaction, voice command, and Neurofeedback interaction.

Eventually, VR technology uses to present Zoo Therapy. During use, the user can freely choose a horse or a dog, and then the user can call the animal to come, let the animal eat, let the animal move freely, or let the animal leave the room.

We divided Zoo Therapy into 5 **modules** according to their functions. In this chapter, we will introduce these 5 modules separately.

The 5 modules are as following:

(1) **Scene Module** - The overall appearance of the environment.

(2) **Animals Module** - Animals in the environment.

(3) **Sound Module** - Environmental and animal sound effects.

(4) **Map Module** - Tracks and patterns of animal movement.

(5) **Human-Computer Interaction Module** - how users and environments interact.

2.1.1. Development engine

We use the Unity Game Engine to develop the Zoo Therapy. Unity is a cross-platform game engine developed by Unity Technologies which gives us the ability to create games and experiences in 3D. It offers a primary scripting API in C#, for both the Unity editor in the form of plugins and games themselves, as well as drag and drop functionality. Unity is easier and convenient to build new 3D environments compared to many other game engines. The engine provides an internal asset store, where programmers or 3D modelers share their creations with everybody in the Unity developer community.

We implement 5 functional modules through different components of Unity and the combination of scripts. The next few sections will introduce them in detail.

2.2. Scene module

This module is designed to create a VR therapy environment for Zoo Therapy, and all the subsequent functional modules are built on this scene.

2.2.1. Room

We built a 3D room based on an asset available on the Unity store. Figure 2.1 (a) shows a screenshot taken from the backside of the room. Figure 2.1 (b) is the hand drawing top view of the room, in which the black objects are the obstacles in the room, such as sofa and table, and the empty places provide the activity space for animals. We adjusted the size and position of the furniture since the animals would walk, run, or perform other activities in the room later.

(a) Real scene room (b) Hand drawing room

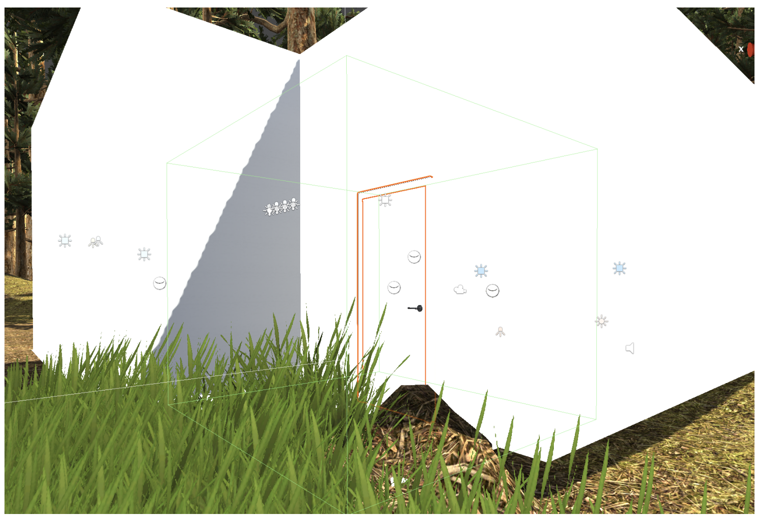
Fig. 2.1. The furniture and the room

2.2.2. Auto-door

In this 3D room, all objects are stationary, except the door that needs to open automatically when the animal approaches and close automatically when the animal leaves. To implement this action, first, we created an open and close animation segment by Unity for the door. Next, we have to activate the door when an animal is approaching or leaving.

An invisible Collider Component is added to animals and the door. The Collider Components define the shape of the door or animals for the purposes of physical collisions, but it does not need to be the exact same shape as the object. We resize the collider of the door to define the space that triggers the opening and closing. In Figure 2.2, the thin green line around the door is the door's collider which forms a big invisible cuboid around the door. We write a script to detect when collisions occur. In Unity, we can configure a collider to either behave like a solid object, so that any other object cannot pass through it, or as a non-solid in which case another object can pass through it. In this case, we don't want to perform collisions visually, so we just use the physics engine in Unity to detect when animals' collider touches the boundary of the door's collider. The door's collider configured as a trigger (using the Is Trigger property) does not behave like a solid object and will simply allow the animal collider to pass through. The OnTriggerEnter function on the door's scripts invokes a function call which activates the Animation Clip that opens the door. When the animal collider passes through the door collider completely, the trigger will call the OnTriggerExit function on the door's scripts, and the function calls the Animation Clip that closes the door. Since all colliders are invisible at running time, the impression is that the door opens when the animal approaches and closes when the animal leaves.

(a) Internal perspective



(b) External perspective

Fig. 2.2. The collider of the door

2.3. Animals module

2.3.1. Appearance

We selected from Unity's resources horses and dogs that were modeled from real animals as our virtual therapy animals that looked friendly, calm, approachable, and well trained as shown in the Figure 2.3.

(a) horse (b) dog

Fig. 2.3. Therapy animals

2.3.2. 3D animation

A texture model asset in the Unity asset store is usually supplied with several animation clips. Animation Clips in Unity are animation data that can be used for animated characters or simple animations. It is a simple “unit” piece of motion, such as (one specific instance of) "Idle", "Walk", "Run", "Sleep" etc. Unity’s Animation System is based on the concept of Animation Clips, which contain information about how certain objects should change their position, rotation, or other properties over time. Each clip can be thought of as a single linear recording. These clips are then organized into a structured flowchart-like system called an Animator Controller. An Animator Controller allows us to arrange and maintain a set of Animation Clips and associated Animation Transitions for a character or object. In most cases, it is normal to have multiple animations and switch between them based on certain conditions. For example, it could switch from a "walk" Animation Clip to an "idle" Animation Clip when an animal need to stop before the sofa and interact with a user. It could switch from a "walk" Animation Clips to an "eat" Animation Clip or alternate between an "idle"

Animation Clip to an "eat" Animation Clip when the user selects the action to look at the animal eating something.

Due to the limitation of room size, we did not use actions and animations such as the horse's "run" and "jump". Also, we want to keep the animal's movements as calm and slow as possible, so we do not use the aggressive actions of the dog such as "attack" and "jump". The actions selected for the horse are: walk slowly, walk fast, eat, idle and stand up. These five actions use four Animation Clips. Walk slowly and walk fast will use the same "walk" Animation Clip, but the playback speed is changed. The dog's animations are more complex, some of the actions are performed by connecting several small Animation Clips. For example, the action "smell" is broken into three small Animation Clips: start to smell, smell, and end smell. The action of "lie down" is divided into: go to lie, lie, end lie. The selected actions of the dog: walk, eat, idle, run, stand up, sit down, lie down, bark, scratch, and smell, are divided into thirteen animation clips in total. Now these animation clips are all independent, we'll explain in details how we use Animator Controller to manager and switch between these Animations Clips to present an animal that can make a coherent actions in our environment.

In Unity, the Animator Controller manages the various animation states and the transitions between them using a so-called State Machine, which could be thought of as a kind of flow-chart, or a simple program written in a visual programming language within Unity. The Animator Controller acts as a “State Machine” which keeps track of which clip should currently be playing, and when the animations should change or blend together.

In the Animator Window of Unity, the structure of the Animator Controller can be created, viewed and modified. It has two main sections: the main gridded layout area, the left-hand Layers & Parameters pane (Figure 2.4). The main gridded layout are use to create, arrange and connect states in the Animator Controller. The left-hand Layers & Parameters pane use to create, view and edit the Animator Controller Parameters. These are variables we define that act as inputs into the state machine.

We created an Animator Controller for each animal to manager and switch at any actions. The basic idea is that an animal is engaged in some particular kind of action at any given time. For example, the horse's typical actions include idle, walk, eat, etc. These actions are referred to as states, in the sense that the animal is in a “state” where it is walking, idling or whatever. In general, the animal will have restrictions on the next state it can go to rather than being able to switch immediately from any state to any other. For example, a running jump can only be taken when the animal is already running and not when it is at a standstill, so it should never switch straight from the idle state to the running jump state. The options for the next state that an animal can enter from its current state are referred to as state transitions.

The set of states, the set of transitions, and the variable to identify the current state together form a state machine. The states and transitions of a state machine can be represented using a graph diagram, where the nodes represent the states and the arcs (arrows between nodes) represent the transitions. In the Layers & Parameters pane, we created some Animation Parameters which are variables that are defined within the Animator Controller that can be accessed and assigned values from animals' scripts. This is how our script can control or affect the flow of the state machine.

In our environment, most of the parameters are boolean parameters, and our script can control which state the animal enters by setting parameters True or False. For example when an animal comes to the sofa to eat. Before it reaches the sofa, it plays the walk Animation Clip. When it reaches the eating position, the eating function in animal's script will be called. This function contains the boolean variables that control walk and eat. By turning off the parameter "walking" and turning on the parameter "eating", the state in the state machine will transfer from walk state to eat state. Then the animation of the animal moves from playing the "Walk" Animation Clip to playing the "Eat" Animation Clip. When the animal finishes eating, the animal script calls the idle function. This function can turn off the parameter "eating" and turn on the parameter "idling", the state in the state machine transfer from eat state to idle state. Then the animation of the animal moves from playing the "Eat" Animation Clip to playing the "Idle" Animation Clip.

The Figure 2.4 shows the dog's Animator Window as an example. Orange state is the default state, animation will start from the default state, and node will be evaluated and will branch to the destination state according to the conditions set. For both the horse and the dog the initial state is walk, and the transition condition is controlled from the animal's script, thus affecting the animation clip switch.

Based on the user's interaction with animals, we created different action function in the animal's script to switch Animation Clips. For horses, there are walk function, eat function, idle function and stand up function. Each function has a variable that turns on that action, and some variables that turns off other possible actions. For the dog is the same. These action functions can be used to control the switching actions of animals in different situations. Besides, in order to diversify the behavior of animals, we also adjust the speed of the Animation Clips to change the action of animals. In the wander state, the horse walks slowly, but when the user summons it, the animal's script will not only call the walk function, but also increase the speed of playing the walk Animation Clip, making the

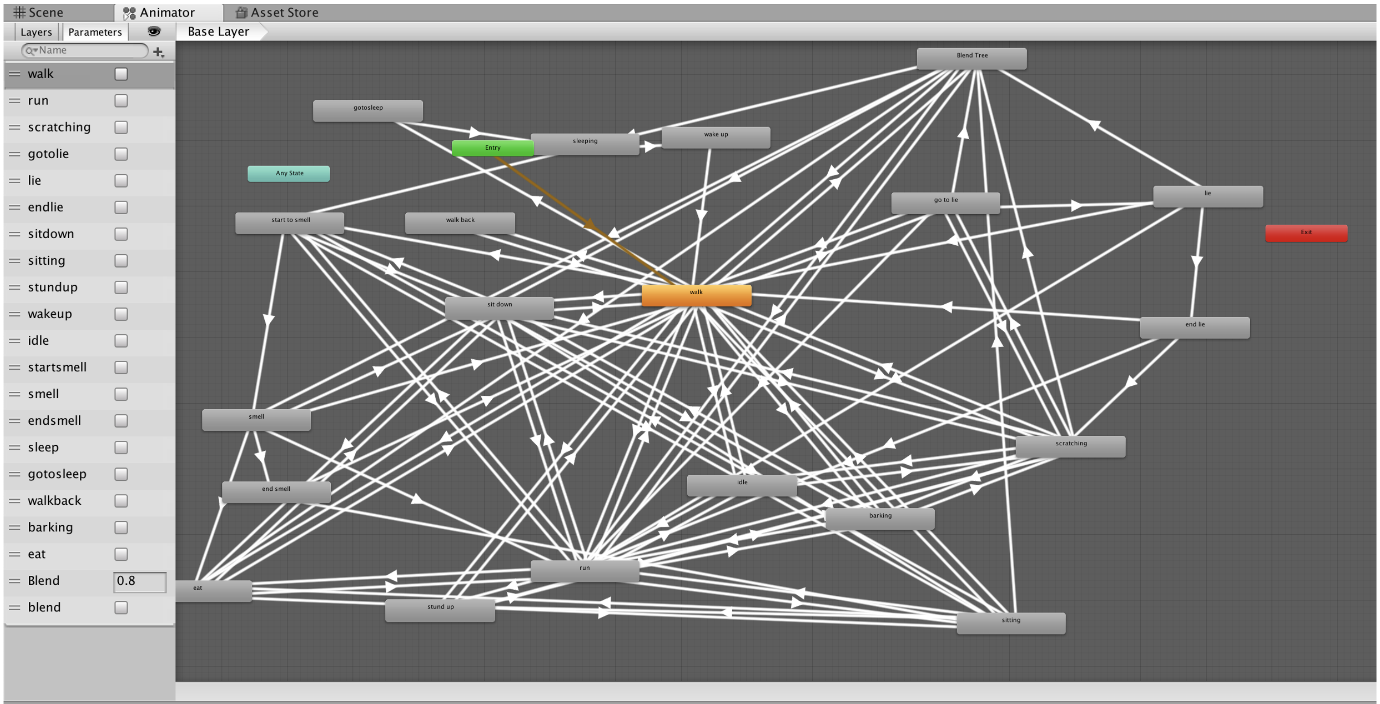


Fig. 2.4. Dog's Animator Window: The column on the left is the parameters for switching actions, and the flow-chart on the right is the dog's Animator Controller

horse looks as if it is walking faster towards the user after receiving the user's command. When the horse returns to wander state, it will return to again start walking slowly.

The free switch of animation is very important for the whole environment, because in the whole interaction process, it is possible to change the animation at any time due to user's instructions. If the content of the script is missing, the variable setting fails, or the state machine creation is not perfect, it may cause the animal behavior to freeze or even make mistakes. Therefore, according to the interaction between users and animals, we simulated different scenes and conditions of animation switching as much as possible, to ensure smooth switching between Animation Clips.

2.4. Sound module

Zoo Therapy is incomplete without background music and sound effects. We used Unity's flexible and powerful audio system to add soothing background music and add different sound effects to the animals in the environment. We prepared several animal sound recordings, such as horse neighing, dog barking, horse walking, dog panting, horse eating, and imported these sound files into Unity. After that, the animal script will call different sound files according to different situations to match the animal's animation, and play them in the 3D environment. The freely switching animation with the corresponding sound effect of each action makes the animals in the environment come to life immediately.

In real life, sounds are emitted by objects and heard by listeners. A listener can tell roughly which direction a sound is coming from and may also get some sense of its distance from its loudness and quality. A fast-moving sound source (a passing police car) will change in pitch as it moves as a result of the Doppler Effect. To simulate the effects of position, we add a Audio Sources Component to each animal to plays back an Audio Clip in the scene. The Audio Clip can be played to an audio listener, the users. As shown in the picture(Figure 2.3), there is a small horn symbol on the animal, which is the sign of Audio Sources. It is invisible when using the environment, but it moves with the animal. So when it playback an Audio Clip, the sound will move with the animal. Unity can then simulate the effects of an animal's distance and position from the listener and play them to the user accordingly. The relative speed of the animal and listener can also be used to simulate the Doppler Effect for added realism.

In order to match different animations, we created different sound effects functions in each animal's script, which read different audio recordings and adjusted the playback speed according to different animations. Audio Clips comes from the different imported sound files. For example, when the horse is walking in the room and receives the command to approach the user. In this process, we use three Audio Clips: walk slowly Audio Clip, neigh Audio Clip and walk fast Audio Clip. When the horse walk slowly in the room, the Audio Source loops playback the walk slowly Audio Clip. The moment it receives the user's command "come", the animal's script calls the neigh function, which plays a neigh Audio Clip in response to the "come" command. At this point, the sound of walk and the sound of neigh are co-existing. After the action of the horse switches to come to the user, horse's Animation Clip will switch from walk slowly to walk fast, the animal's script calls the walk-fast sound effect function, in order to match the walk fast animation. The function plays the walk fast Audio Clip in a loop instead of the just walk slowly Audio Clip.

Table 2.1 shows the corresponding action of the animal, the Animation Clips used and the playing speed, the Audio Clips used and the playing times under different commands. The table is partitioned for each animal: the horse and the dog. The first line of each part is the instructions that will be received. For the horse, it can receive five different instructions, namely wander, come, eat, stand up and leave. The instructions for dog are wander, come, eat, lie down and leave. Under each command, we have the action that the animal will perform, the Animation Clips that may be used, the playing speed of the Animation Clip, and the Audio Clips that will be used, as well as the playing times and speed.

Table 2.1. Horse's Animation and Audio Clips matching table

Horse					
	Wander	**Come**	**Eat**	**Stand up**	**Leave**
Actions	Walk slowly	Walk fast	Eat	Stand up	Walk fast
Animation Clips	Walk (Speed:0.85)	walk (Speed:1) Idle	Eat Idle	Stand up	Walk (Speed:1.2)
Audio Clips	1.Neigh 02 (once) 2.Walk slowly (loop)	1.Neigh 01 (once) 2.Walk fast (loop)	1.Neigh for eat (once) 2.Sound of eating (loop)	Neigh01 (once)	Neigh 03 (once)
Dog					
	Wander	**Come**	**Eat**	**Lie down**	**Leave**
Actions	Walk	Run Sit down	Smell Eat	Lie down	Run
Animation Clips	Walk	Run Walk Start to smell Smell Sit down Sitting Stand up	Start to smell Smell Walk Eat Sit down Sitting Stand up	Run Walk Scratching Go to lie Lie End lie	Run
Audio Clips	1.Barking 01 (Once) 2. Walk -Panting(loop) (Speed:0.5)	1.Barking 00 (Once) 2. Run-Panting (loop) (Speed:1.1) 3. Sit-Panting (loop) (Speed:0.25) 4. Smell -Panting (loop) (Speed:0.4)	1.Barking 00 (Once) 2. Sit-Panting (loop) (Speed:0.25) 3. Smell -Panting (loop) (Speed:0.4) 4. Eat-Panting (loop) (Speed:0.3)	1.Barking 00 (Once) 2. Panting for scratching (loop) (Speed:0.2)	1.Barking 01 (Once) 2. Run-Panting (loop) (Speed:1.1)

2.5. Map module

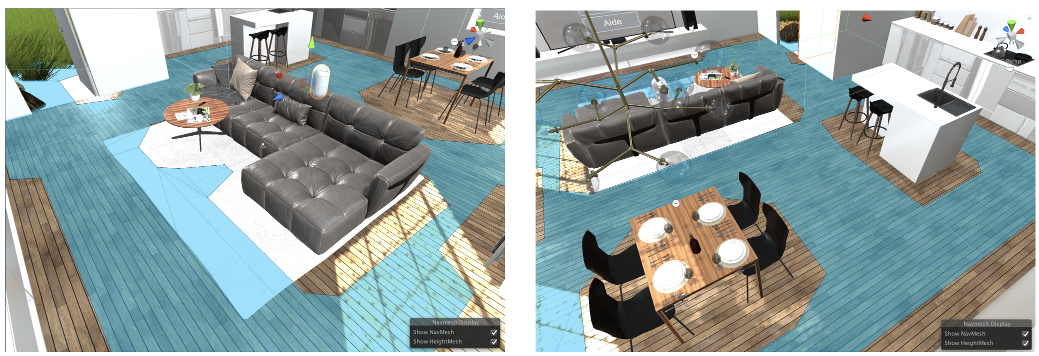
2.5.1. Navigation systems in Unity

Unity's navigation systems allows us to create our animals that can intelligently move around the environment. It gives animals the ability to understand that they need to avoid obstacles likes sofa, table, chairs and in the room..

Building a NavMesh

We need to build a NavMesh (short for Navigation Mesh) for our room. NavMesh is a data structure which describes the walkable surfaces of the game world and allows to find path from one walkable location to another in the environment. The animal can enter the room through the door and walk in the feasible area without going through the wall or bumping into objects in the room.

The walkable area for animals defined in the NavMesh is shown in Figure 2.5 as a blue overlay on the floor.



(a) (b)

Fig. 2.5. A NavMesh in the room

Making an animal Patrol Between a Set of Points

According to the user's interaction with the animal, the map can be divided into three states:

(1) Wander mode: This is the default mode when the user is not interacting with the animal. It is in a state of free walk inside the room.

(2) Interactive mode: The animal receives instruction from the user to do tasks inside the room, such as come, eat, stand, lie down.

(3) Leaving mode: The animal receives the instruction to leave and leaves the room directly.

In the beginning of the Zoo Therapy's feature, the animal is in wander mode, and can walk automatically in the walkable area. The navigation system of Unity can be used to implement this behaviour, we can get a patrol pattern by creating a set of key points that are "useful" for the animals to pass through and visiting them in some kind of sequence.

Figure 2.6 is a hand-painted top view of the room. The circles with numbers indicate key points for animals to pass through or stay. Point 00 is start and end point. Point 08 is the point at which the animal interacts with the user, we call it Interaction Point. The directional arrows in black indicate the direction of the animal's movement and possible routes. In wander mode, the animals will follow the 0 -> 1 -> 2-> 6 -> 7 -> 3 -> 4 -> 5 -> 6 -> 7 -> 9 -> 0 path. The animals switch to idle when they arrive at yellow circles and switch to eat when they arrive at green circles. In the other two modes, when animals reach these circles, they just go by, not stay. In the interactive mode, depending on the position of the animal, there are 0->9->8, 2->6->7->9->8, 3->4->7->9->8, 5->6->7->9->8, four fixed paths, and there are three fixed paths in the leaving mode, there are 2->6->7->9->0, 3->4->7->9->0 and 5->6->7->9->0.

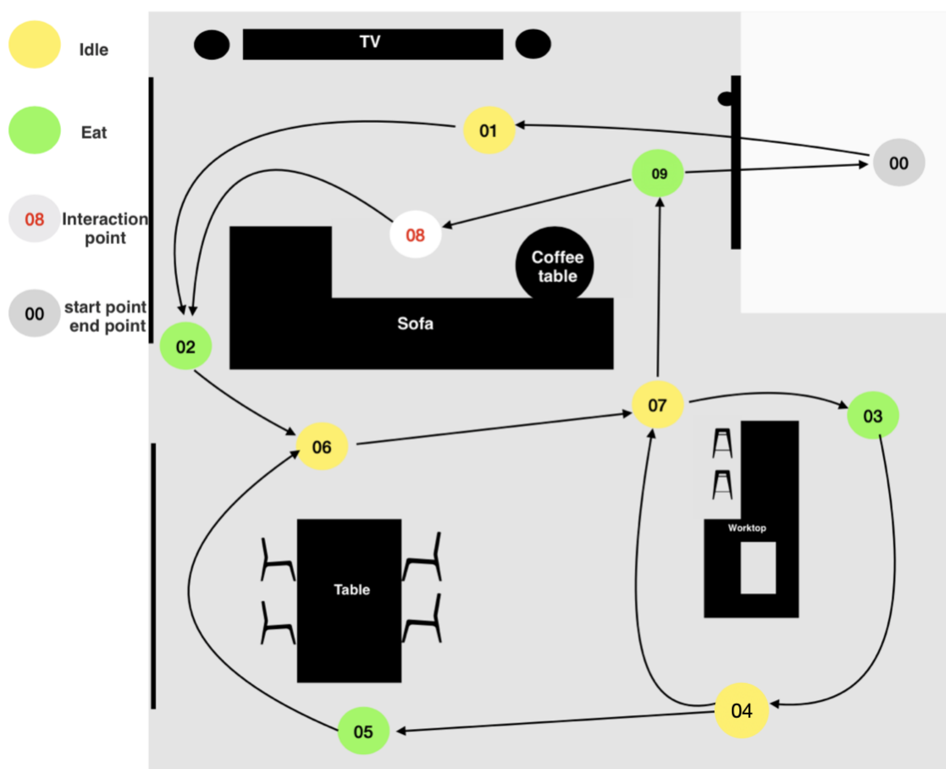


Fig. 2.6. A hand-painted to view of the room with key points

These paths are all fixed. It is easy to see from this first draft (Figure 2.6) that the direction of movement of the animal and route order are the same for each interaction or leaving, and the paths to the Interaction Point is predictable. This approach makes users to feel bored after several interactions, because it can be noticed that the animals' are moving in predefined paths and further, user's the engagement is inevitably reduced. So we improved pathfinding system on the same NavMesh to make the animals less rigid.

2.5.2. Pathfinding System for Zoo Therapy

Since it's not very interesting to have predefined paths, we explore new ways of pathfinding to improve the navigation of animals. Also, we want to make the animals seem more intelligent than just going around in the same route. Our objective is that the animals can freely choose their direction and would randomly choose a route from all possible paths to go to the Interaction Point when the user calls them, rather than taking a single fixed path as in the wandering mode. So an animal's path is more unpredictable and random, and closer to the behavior of animals in the real world.

In order to make the animals walk more freely, we added more key points in the room. In order to walk in any direction, we added more arrows in both directions connecting the key points, so that the animals could reach any key point in the room from all directions. But although the arrows are bidirectional, it just means that the horse can move in any direction, not that the horse can move forward and backward at will. This is due to the limitation of animal animation. We do not have backward animation for the animals, so currently animals can only walk forward, which means that they can only reach the point in front of themselves. We created a directed graph on the map, including 17 vertices and 46 edges, and the distribution in Zoo Therapy is shown in the Figure 2.7: Point 07 is Interaction Point in this version. Point 09 is start and end point. Point 15 is a place where the horse can stand up.

This system mainly needs to realize the following three parts:

(1) In wander mode, the animal chooses freely its direction forward.
(2) In interactive mode, the animal chooses randomly a path to the Interaction Point based on the instruction which it receives.
(3) In leaving mode,the animal leaves the room by the shortest path.

Select randomly the next point to go

In the wander mode, the animal can choose freely the next point to go, which is done in the graph by choosing randomly any vertex adjacent to the current node. First, we

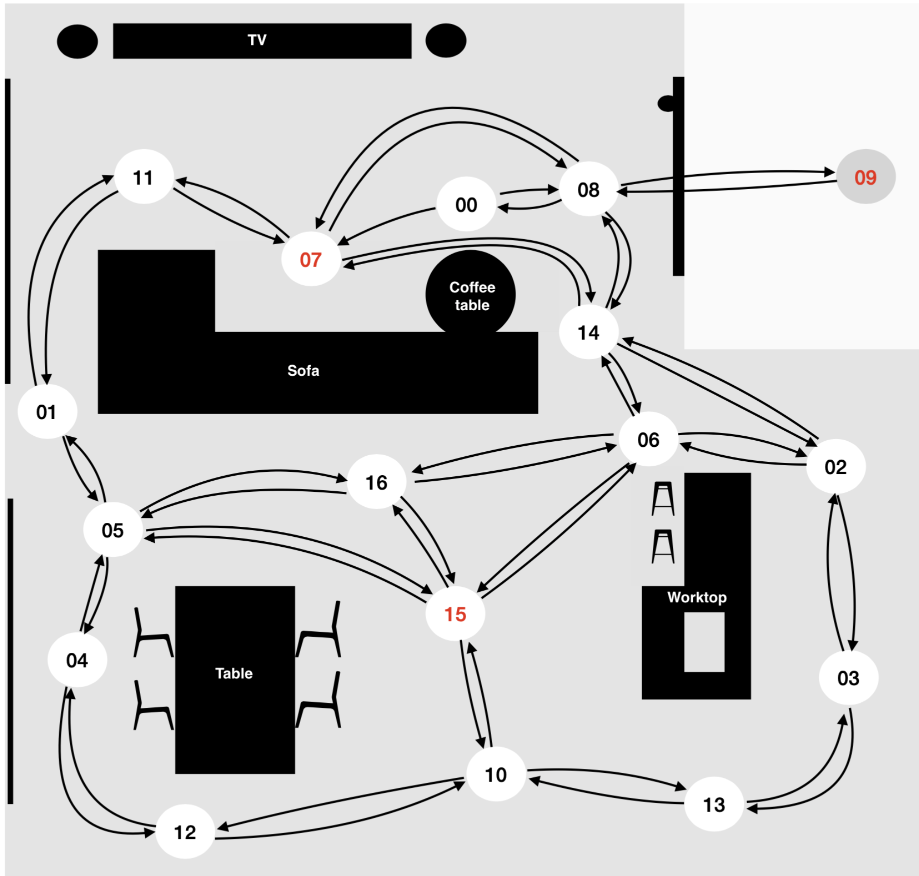


Fig. 2.7. Key Points Map of pathfinding system for Zoo Therapy

determine the animal's current position as the starting point and the direction of the vector connecting the animal's body to the head as the forward direction that the animal, so we can know that the animal is going from this starting point to this forward direction. Next, we get all the vertices adjacent to the starting point, and find next valid points which are points in front of the animal's head. This is done because the field of vision (FOV) of the animals is restricted to 180 degrees in front of the face of the animal. Finally, we randomly select a point from the valid points as the target point. The target point is where the animal will go. When the animal reaches this target point, the target point becomes the starting point, and the system will calculate the next target point in the same way. In this way, in the wander mode, will randomly select the next point and move forward with each transfer without moving on a predefined path. We can see more clearly how the algorithm is implemented during the wander through the following example.

We take the example of the horse in wandering mode. In addition to the elements displayed in the previous Key-Points-Map(Figure 2.7), we added a horse and green shaded parts, shown as Figure 2.8. We can directly see the horse's current position and forward direction from the picture, the green shaded part is the field of vision of the horse, and the point inside is the point in front of the horse's head (Figure 2.8). We use Table 2.2 to show the update of the points of each step at each transfer.

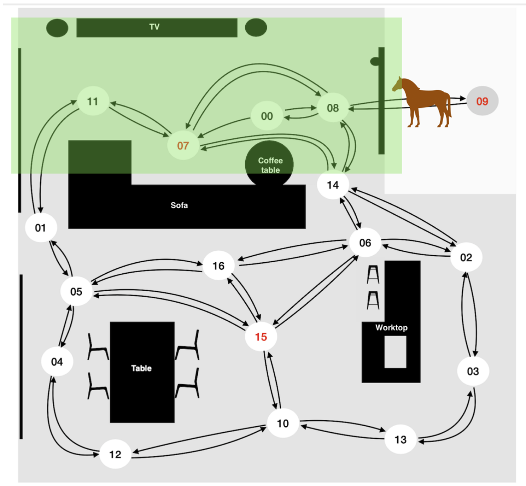
Firstly, the horse departs from Point09 (Figure 2.8 (a)). At this moment, Point09 is the starting point, the forward direction is the position of the door in front of the horse. Next, we can see that only Point08 is connected to Point09, and that Point08 also happens to be within the horse's field of view. So Point08 is the only valid point for the horse at the current position. Then we don't need to randomly choose a point as the next point, the target point is Point08. And Point08 will be the starting Point of Transfer 2 (Figure 2.8 (b)).

When the horse arrives at the position shown in Figure 2.8 (b), we can see that the current starting point is Point08, and the vertice adjacent of Point08 are Point00, Point09, point07 and point14, among which Point09 is not in front of the horse, that is, not in the green area, which can be ignored. The valid points are Point00, Point07, Point14. We pick a random point from these three valid points and assume that horse's target point is Point14. (As shown in the 2 row of the Table 2.2).

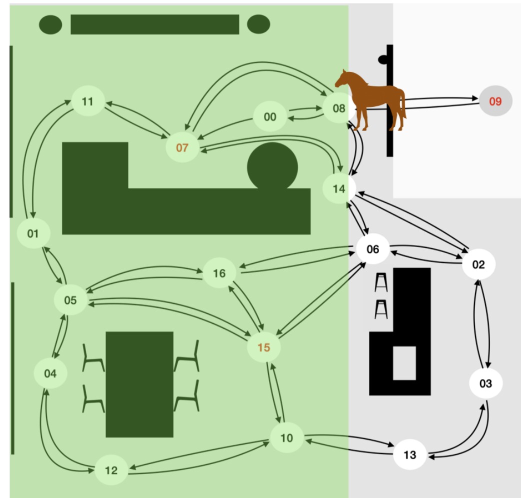
Then the horse goes to Point14, and the vertices adjacency and the valid points of Point14 are shown in the Figure 2.8 (c) and the 3th row of the Table 2.2, and the next target point is randomly selected to be Point06. Figure 2.8 (d) and the 4th row of the Table 2.2 shows the horse goes from Point06 to Point15, and so on.

Table 2.2. Transfer table

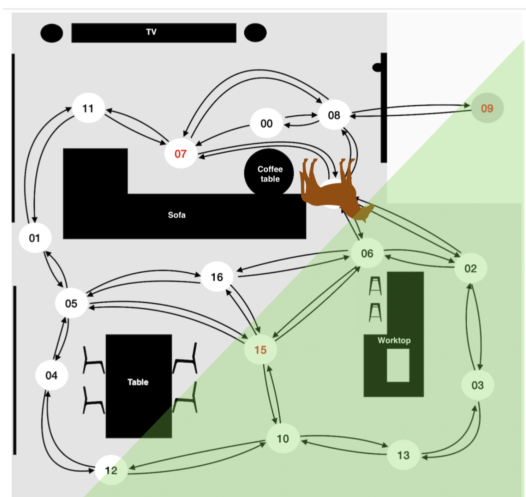
Transfer	Starting Point	Vertices adjacent to Starting Point	Valid Points	Target Point
1	Point09	Point08	Point08	Point08
2	Point08	Point00 Point09 Point07 Point14	Point00 Point07 Point14	Point14
3	Point14	Point07 Point08 Point02 Point06	Point02 Point06	Point06
4	Point06	Point14 Point15 Point02 Point16	Point15 Point16	Point15
5	Point15	Point05 Point06 Point10 Point16	Point10	Point10
6	Point10	Point15 Point12 Point13	... ...	... ...
7	... ...			



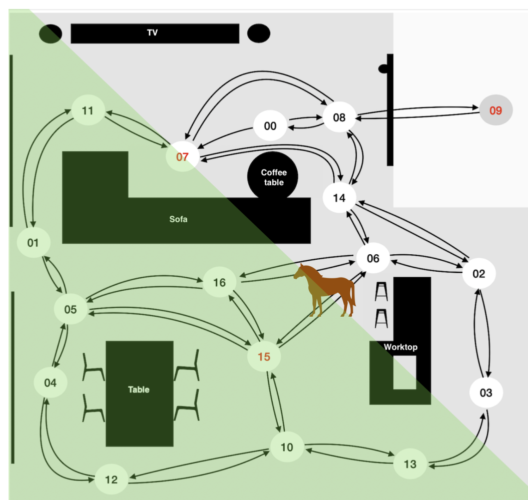
(a) Transfer 1



(b) Transfer 2



(c) Transfer 3



(d) Transfer 4

Fig. 2.8. An example in wander mode

In the wandering mode, the animals will move freely within these key points in this way.

Random path to Interaction Point

When the user wants to interact with the animal, the animal will stop the wander mode and turn on interaction mode, animals will go to the point07 in front of the sofa, or point15 which are the Interaction Points to interact with the user. So how does the animal go to point07 or point15 from its current position, and how to choose the path? This can be divided into the following 5 steps:

Step 1: At the moment when the user summons the animal, we immediately determine the position of the animal. Then, We use our BFS algorithm (Algorithm 1) to generate all paths from this position to destination point depending on the instruction of the user. We will describe this algorithm in detail in Section 2.5.3 BFS for Zoo Therapy.

Step 2: Delete all paths that require the animal to go backwards from these paths generated by step 1.

Step 3: Among these paths obtained from step 2, we will use the law of cosines described in Section 2.5.4 to screen them. if the curve formed by the path is less than 90 degrees in certain area, it means that the animal turns too much at this place, the path will be deleted.

Step 4: After the first three steps, all the remaining paths can reach the destination point, we choose one randomly form them.

Step 5: If after the first three steps, the remaining route is 0, then the animal will select randomly a point to go in the way of wander mode, update the position, recalculate the path to the Interaction Point from step 1.

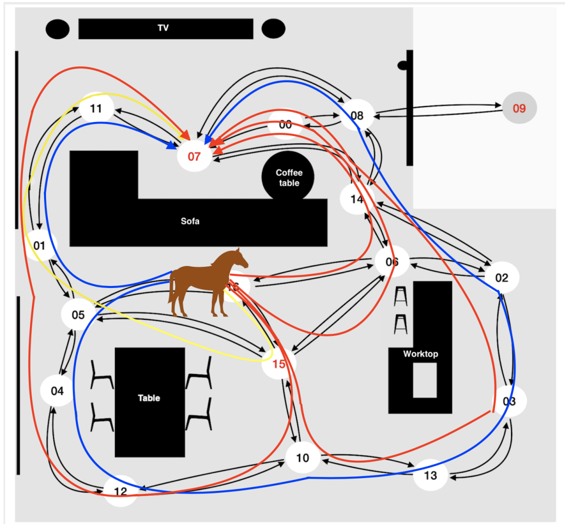
Let's look at an example (Figure 2.9).

Step 1. We assume that the horse walks to the position in the Figure 2.9 (a), Point16, and the user calls it, then the system will generate all the paths from Point16 to Point07. Due to too many paths, only a few representative routes are drawn in the figure. Different colored routes correspond to the next steps.

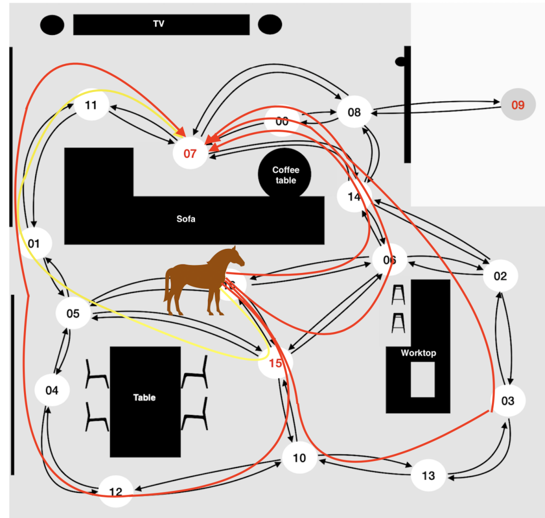
Step 2: The blue lines in the picture need the horse to go backwards or turn around, we need to delete them. After that, the yellow and red routes are left, as shown in Figure 2.9 (b).

Step 3: Looking at the yellow path in the Figure 2.9 (b), the section from Point16 passing Point15 to Point05, the angle is too small to turn around in the room, so this route should also be discarded. After that, the red routes are left, as shown in the Figure 2.9 (c).

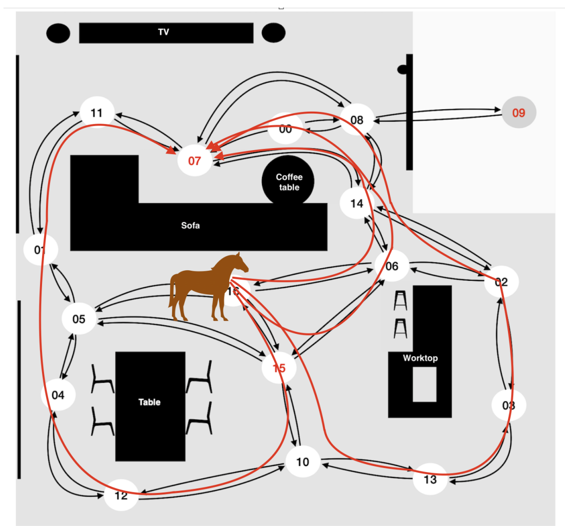
Step 4: Choose one randomly from the remaining red path to Point07. The selected path is shown in bold red lines in the Figure 2.9 (d). After the path is chosen, the horse follows this path to the Interaction Point.



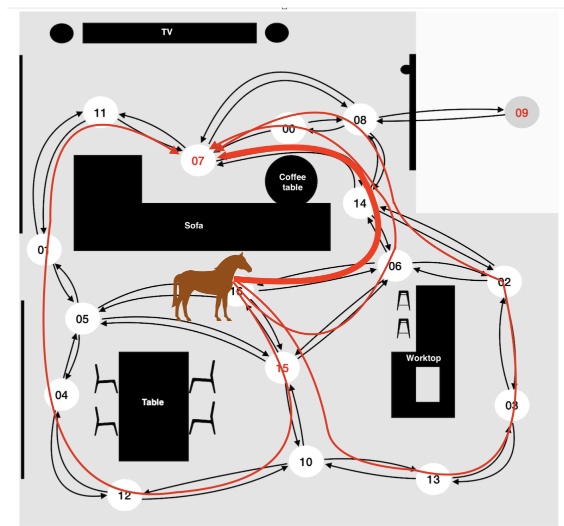
(a) Step 1



(b) Step 2



(c) Step 3



(d) Step 4

Fig. 2.9. Path selection in interaction mode

Shortest path for leave the room

When a leave command is issued, the animal stops all the tasks, the leaving mode is become active and it prepares to leave. When leaving mode is turned on, the animal immediately takes the shortest path to leave the room and leaves.

When the animal needs to leave the room, the destination point becomes Point09. The way to generate the route is the same as the way in the interaction mode, except that instead of choose randomly a route, the shortest one is selected.

Continuing the previous example, if the destination point is changed to Point09. After the first step, all the paths are generated with bread first search (BFS) of the network of the points in the room, the second step removes the backward paths, and the third step removes the small angular paths, the shortest path is obviously the one indicated by the bold red line, from Point16 to Point06, Point14, Point08, and finally to the destination Point09, as shown in Figure 2.10.

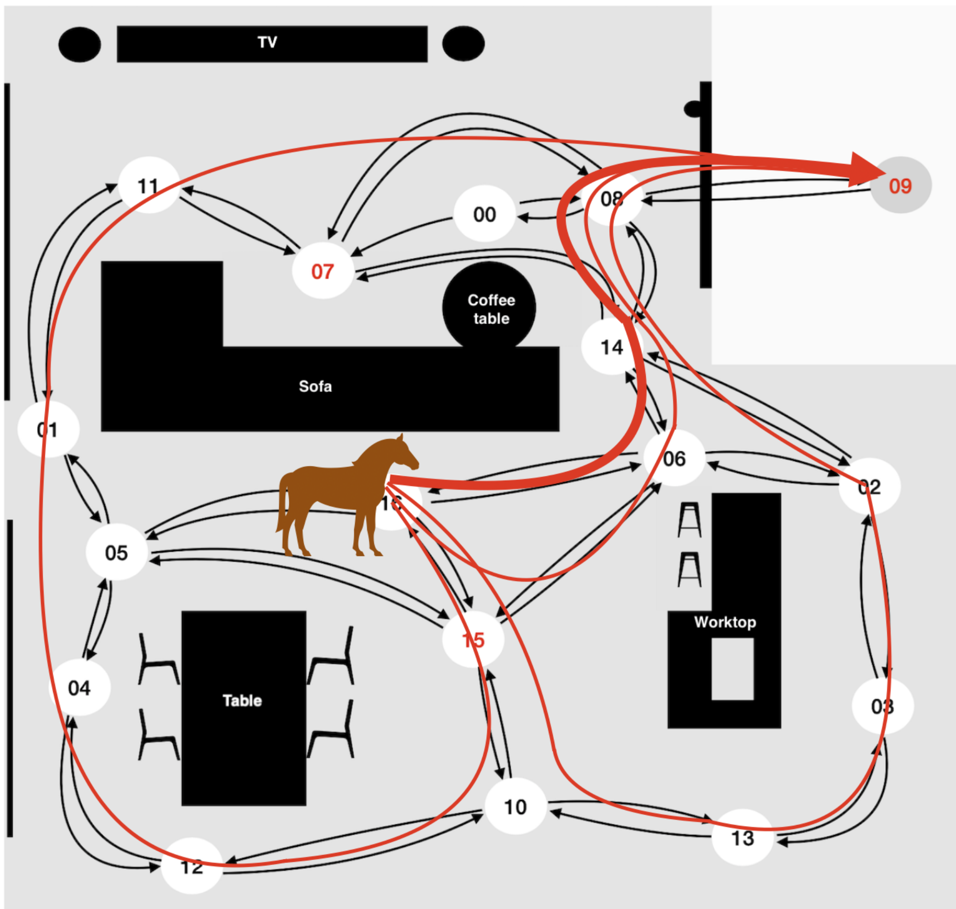
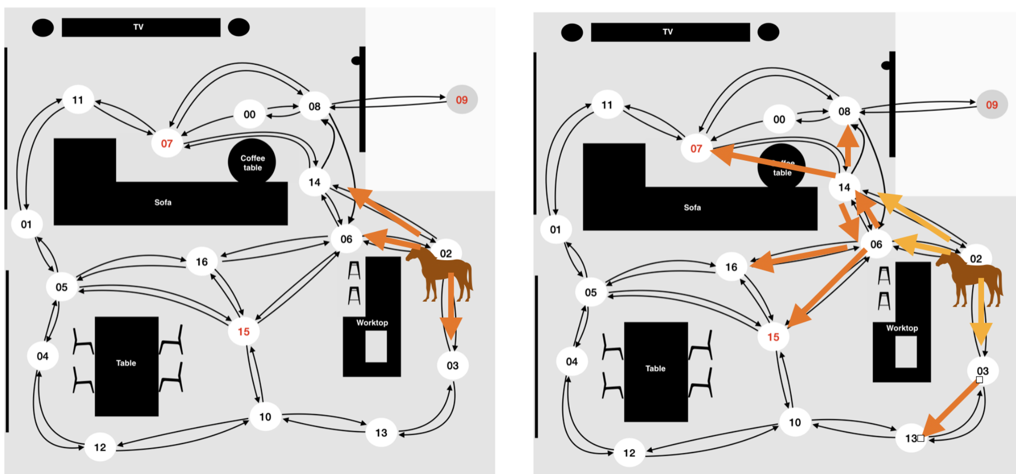


Fig. 2.10. Paths for leave this room, the bold red line is final leaving path

2.5.3. Breadth-first search (BFS) algorithm for Zoo Therapy

Whenever the user gives interactive instruction, whether it is coming, leaving, eating or standing up, pathfinding system will find all paths from the current position c to the destination point d through the BFS algorithm (Algorithm 1). These paths are then filtered based on constraints to obtain the final execution path.

Given the directed graph we set on the Zoo Therapy's map, the current position point c of the animal at the moment the interactive command is received by Unity, there's also the point which is destination point d. We want to find all the paths from c to d, and how BFS does. It starts at c, look for d in all the vertices that only one edge can reach, like Figure 2.11 (a). If d is not found, look for d in the vertex of the two edges away from c (Figure 2.11 (b)), and repeat until you find destination point d (Figure 2.11 (b)). Taking the position of the horse in Figure 2.11 as an example, horse receives the "stand up " command from its current position, then the current position point c is Point02 and the destination position d is Point15.



(a) The vertex of one edge away from current position point

(b) The vertex of two edges away from current position point

Fig. 2.11. The BFS for Zoo Therapy. Horse receives the "stand up " command from its current position c Point02 and the destination position d is Point15.

This algorithm (Algorithm 1) uses a queue to hold all possible paths from starting point c to destination point d. Put the path in the queue, then do the following until the queue is empty:

(1) Take the first path in the queue and check that the last point of the path is d. If it is, this is one of the paths from point c to point d. Store the path in the result list.

(2) If the last point of the path is not point d, the n unmarked vertices adjacent to this point are added to the end of the path, generate new n paths, and store this n paths in the queue.

Using the same example of the horse at Point02, and destination point is Point15. Figure 2.12 shows the steps of our algorithm.

Start at the top left corner of the Figure 2.12. When initialized there is only one path in the queue, the starting point is 2.

- Take out the first path in the queue, [2], and check whether the last point of this path is our d. 2 is not 15, three unmarked vertices adjacent to 2 are [3, 6, 14]. These three points

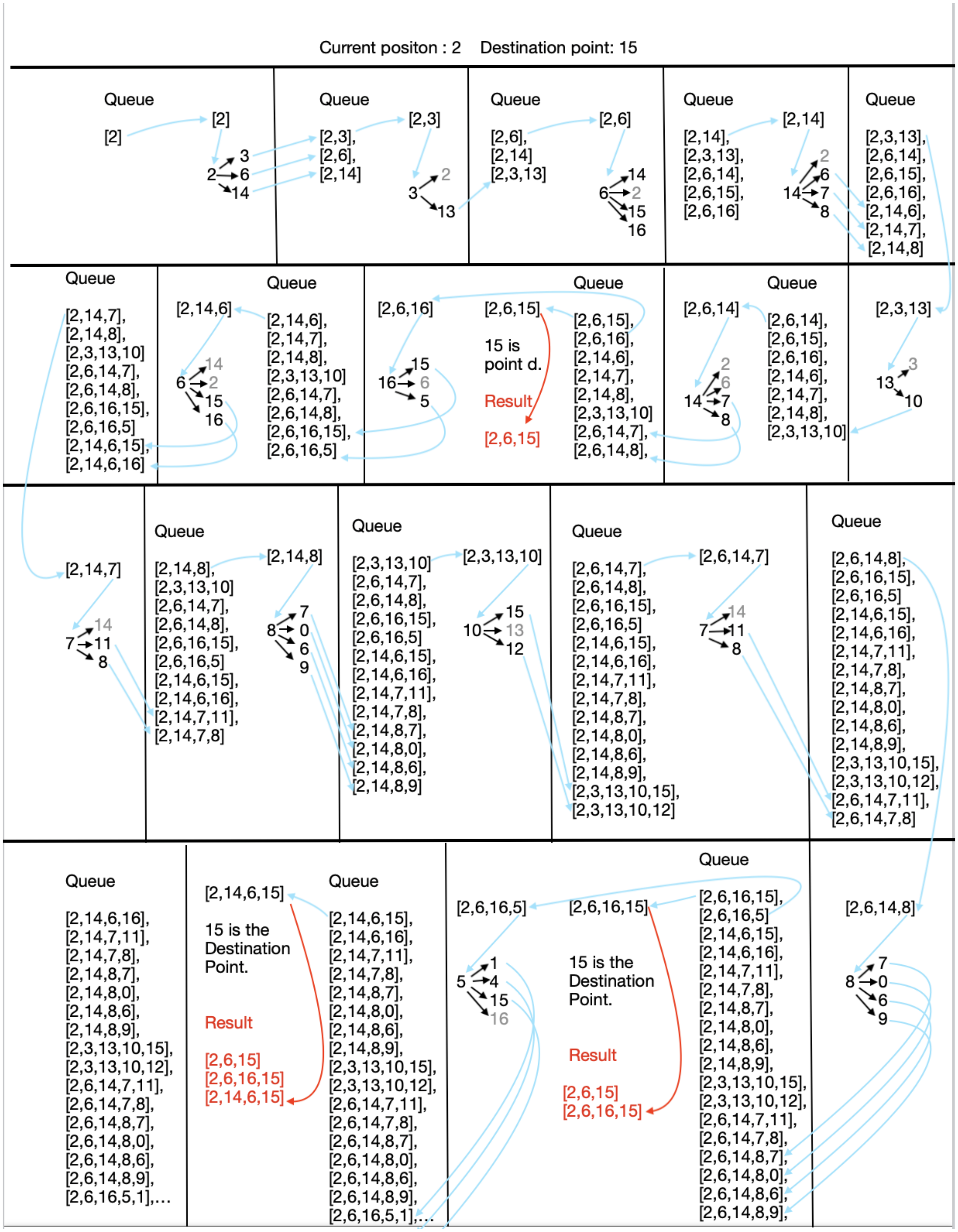


Fig. 2.12. Example of the BFS for Zoo Therapy. The horse's current position c is Point02, destination point d is Point15. A portion of the path from c to d with BFS is shown here.

Algorithm 1 Find all paths from current position c to a destination point d using BFS

```
Initialization
Queue<List<int» q;
List<List<int» result;
List<int> path;
path.Add(s);
q.Enqueue(path);
while q is not empty do
    get the frontmost path from queue
    if lastnode of this path is destination then
        result.Add (path)
    else
        for each i = 1,2... all the vertices connected to the lastnode extracted from path
        do
            if the vertex is not visited in current path then
                create a new path from earlier path and append this vertex
                insert this path to q
            end if
        end for
    end if
end while
return result
```

are added to the end of path [2] to generate three new routes [2, 3], [2, 6], and [2, 14], which are stored in the queue.

- Repeat. Take out the first path in the queue, at this point is [2, 3], and check whether the last point of this path is d, 3 is not 15. Two vertices adjacent to 3 are [2, 13], where 2 is already in the path [2,3], will not be added. So only one new path [2, 3, 13] will be generated and added to the queue.

-Repeat. Take out the first path in the queue, at this time it is [2, 6], and 6 is not 15, so check the points connected to the 6 are [14, 2, 15, 16], among which 2 is already in the path and can be ignored. So three new routes are generated [2, 6, 14], [2, 6, 15], [2, 6, 16] and added to the queue.

Repeat until the red arrow appears and the last point of the path [2, 6, 15] is our target point 15, then the path will be added to the result list. In the same way until the queue is empty. Return result list, which is all the paths from 2 to 15.

In Zoo Therapy, every time an instruction "come", "eat", "stand up" or "leave" is executed, the map passes the animal's current position and the Interaction Point as destination point contained in the instruction to the algorithm Algorithm 1, generates the paths, and then further filters it to obtain the final path.

2.5.4. Effective path angle

Due to the limited space in the room, the body of the horse is relatively large. If the path we choose needs to turn at a large angle, the movement of the horse will be abrupt and not smooth. In some narrow indoor areas, such as from Point02 to Point03, or Point04 in the room, as shown in Figure 2.13. If the animal turns around here, it will hit an obstacle next to it, causing it to get stuck. So we added a corner condition to remove some paths that didn't pass the angle requirement.

According to the Law of Cosines, we can get the angles of a triangle if one knows the three sides. If the sides of a triangle are a, b, and c. The three angles are $A(\alpha)$,$B(\beta)$,$C(\gamma)$, in ΔABC,we have:

$$\gamma = arccos(\frac{a^2 + b^2 - c^2}{2ab}) \tag{2.5.1}$$

Where a, b, and c we can figure out by the distance between the two points. Here c is the distance between point A and point B, the coordinates of A and B are $A(x_1,y_1)$,$B(x_2,y_2)$, so

$$c = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{2.5.2}$$

And similarly, you get a and b.

Since the points in the map are fixed and the coordinates of the points are known from Unity, we only need to pass in three points to verify whether this part of path does meet the angle requirement. Let's take Figure 2.13 for example. Assuming the current position of the horse is Point16 and the destination is Point07, the generated paths by BFS includes the red one in the Figure 2.13, 16-06-15-05-01-11-07. To verify whether this path meets the angle requirement. We start at the first point of the path and pass the coordinates of three consecutive points to the check-angle-function at a time. Keep check the path until the angles formed by each three consecutive points on the path are all qualified and the path is reserved, or there is a section of path angle is unqualified, delete this path. And continue to check the next path. For this red path, the first section to check is the 16-06-15's angle, as shown in the Figure 2.13.The coordinates of the three points in Unity are

$$\text{Point16}(-0.546, -1.812) \quad \text{Point06}(1.23, -1.39) \quad \text{Point15}(-0.3, -3.27)$$

Put it into the Equation (2.5.2), the three side distance can be obtained:

$$\text{side 16-06} = a = \sqrt{((-0.546) - 1.23)^2 + ((-1.812) - (-1.39))^2} = 1.8254478902450215$$

$$\text{side 06-15} = c = \sqrt{(1.23 + 0.3)^2 + ((-1.39) + 3.27)^2} = 2.4239018131929355$$

$$\text{side 16-15} \;= b = \sqrt{((-0.546)+0.3)^2 + ((-1.812)+3.27)^2} = 1.4786074529772937$$

And then you put the a,b,c into the Equation (2.5.1), and you get:

$$\gamma = arccos(\frac{a^2+b^2+c^2}{2ab}) = 37.49395097718702 \tag{2.5.3}$$

We set that if there are three points in the path with an angle less than 90 degrees, it means that the horse needs to turn too large at that point. We will delete this path. We get 16-06-15's angle from Equation (2.5.3) is 37.5 degrees, so this path will be deleted. Continue to check other paths.

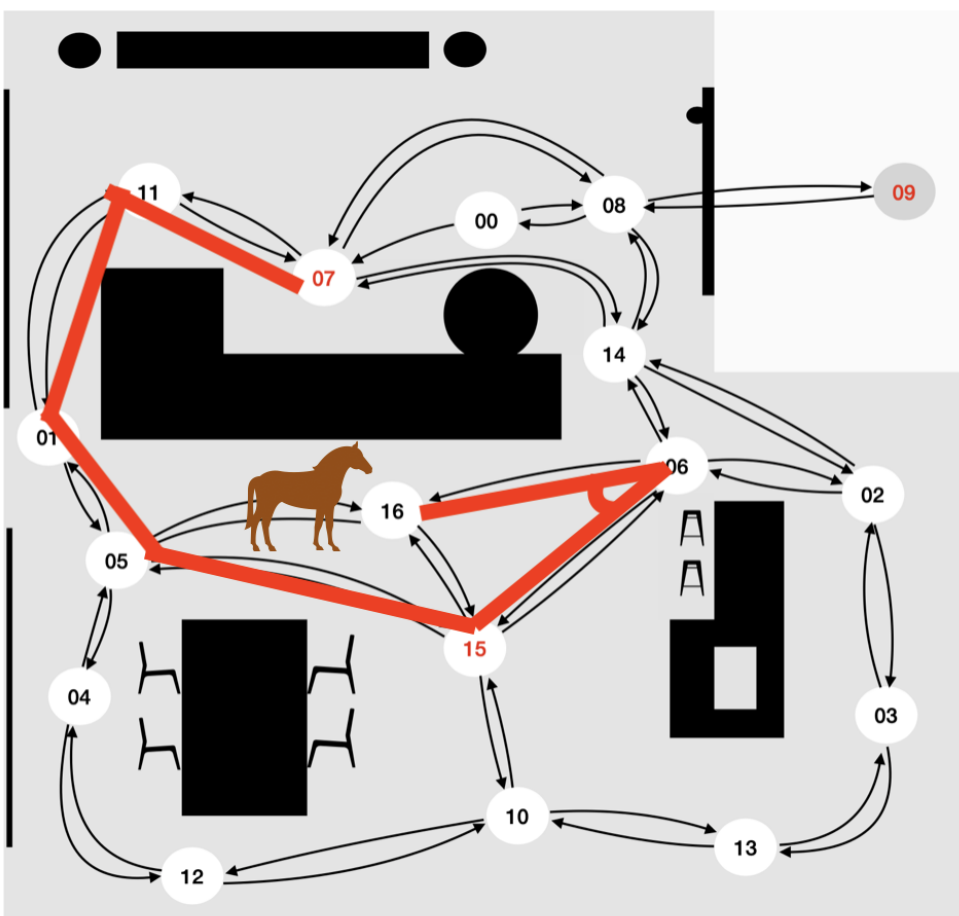


Fig. 2.13. Check whether the red route meets the angle requirement

2.6. Human-Computer Interaction module

Once the environment is ready, how can the user interact with the animal in the environment? We need the environment to accept the user's instructions and let the animal respond accordingly.

Zoo Therapy supports the coexistence of three interaction methods, divided into subjective interaction and non-subjective interaction.Subjective interaction are interactions where instructions are actively issued by users, such as menu panel and speech instruction. Non-subjective interaction is that the instructions are not issued by the users, but by the animal. This is done by the Neurofeedback system according to the user's real-time EEG emotional value to guide the animal to complete.

There are four instructions for subjective interaction, five for non-subjective interaction.To differentiate the animal's active interaction behavior from the user's instructions and make the user feel more novel, non-subjective interaction (Neurofeedback interaction) has one more instruction than subjective interaction.In parentheses, instructions that only the Neurofeedback system can issue are given.

Instructions for two animals:

For the horse: come, walk, eat, leave, (stand up).

For the dog: come, walk, eat, leave, (lie down).

The menu panel in the three interactive methods is created using the user interface (UI) system in Unity, which we will introduce in this chapter. The speech instruction system and Neurofeedback system will be used as two interfaces to describe the development process in detail in the next chapter (Chapter 3).

First, let's see how the animal receives the user's instructions and executes them.

2.6.1. Execute and switch instructions

Let's take the horse for example. In the animal's script, we created 5 Boolean values as five switches for the five instructions, namely Coming, Walking, Stand up, Eating and Leaving. And create five instruction functions, in each instruction function, not only set to turn on this instruction switch and turn off other instruction switches, but also plays the corresponding Animation Clip, Audio Clips and pathfinding system of the animal under this instruction. For example, ComeHere Function includes Coming value is True, Walking, Stand up, Eating and Leaving are False, Walk-Fast Function, Walk-Fast-Sound Function, Neigh Function, Pathfinding system in interactive mode, etc. In this way, when the user issues different instructions, the animal will execute different instruction functions. When one instruction function is started, other instructions are closed. The animal can switch and execute the instruction for the first time when the user issues the instruction. If the same instruction is issued continuously, the instruction function will only play the Audio Clip of the animal's call again in response, and will not recalculate the path. Additionally, the Leave instruction is a special task, and the issuing of this instruction is equivalent to the end of the game. The Leave instruction function stipulates that when this instruction is executed, any other instruction is ignored until the animal leaves the room. Having an animal perform different instructions is managed by the process of calling different instruction functions. So how do users trigger these functions?

2.6.2. Menu panel

For interacting with animals, at first, we created four 2D buttons corresponding to different instructions: Come, Eat, Walk, Leave. (the action of stand up of the horse may cause discomfort to the user, so it is not optional in the subjective interaction. This action occurs in non-subjective, Neurofeedback system interactions) Each button has a single event called On Click that responds when the user completes a click. The button is can initiate an action who was defined in animals' scripts when the user clicks and releases it. If the mouse is moved off the button control before the click is released, the action does not take place. For example, when a user clicks on Come-Button, the button initiates the ComeHere function in the animals' script, and the animal executes this function. Eat-Button corresponds to the Eat Function of animal's script, Walk-Button to the Walk Function of animals' script, and Leave-Button to the Leave Function of animals' script.

When creating 2D buttons, these buttons are only displayed in 2D space, that is, on the screen of our computer or mobile phone, but in VR environment, the environment is a 3D space, so 2D buttons are not applicable, and there is no mouse to click on the button when using VR headset. Besides, four buttons can only control one animal, how to switch between animals, how to start and end interactions, we will add 3D control panels, 3D buttons and changing the input system.

In order to interact with animals and cooperate with VR immersive 360-degree perspective, we made the camera look around in the way of human eyes, so that when the user wears VR helmet, the camera can realize 360-degree view. We set a 3D capsule on the sofa to simulate the human body, and put the camera on the upper part of the capsule to simulate the position of the eyes. The displacement of the mouse is the rotation displacement of the user's head, so as to simulate the perspective of people sitting on the sofa to freely watch the surrounding things.

The button and the panel where the button is located are on the TV directly opposite the sofa. We switch the panel and animal's action by click button. When the user clicks on a button, the panel in which the button is located is hidden and the panel to which the arrow points is opened. If the button is an action button, the animal will act accordingly.

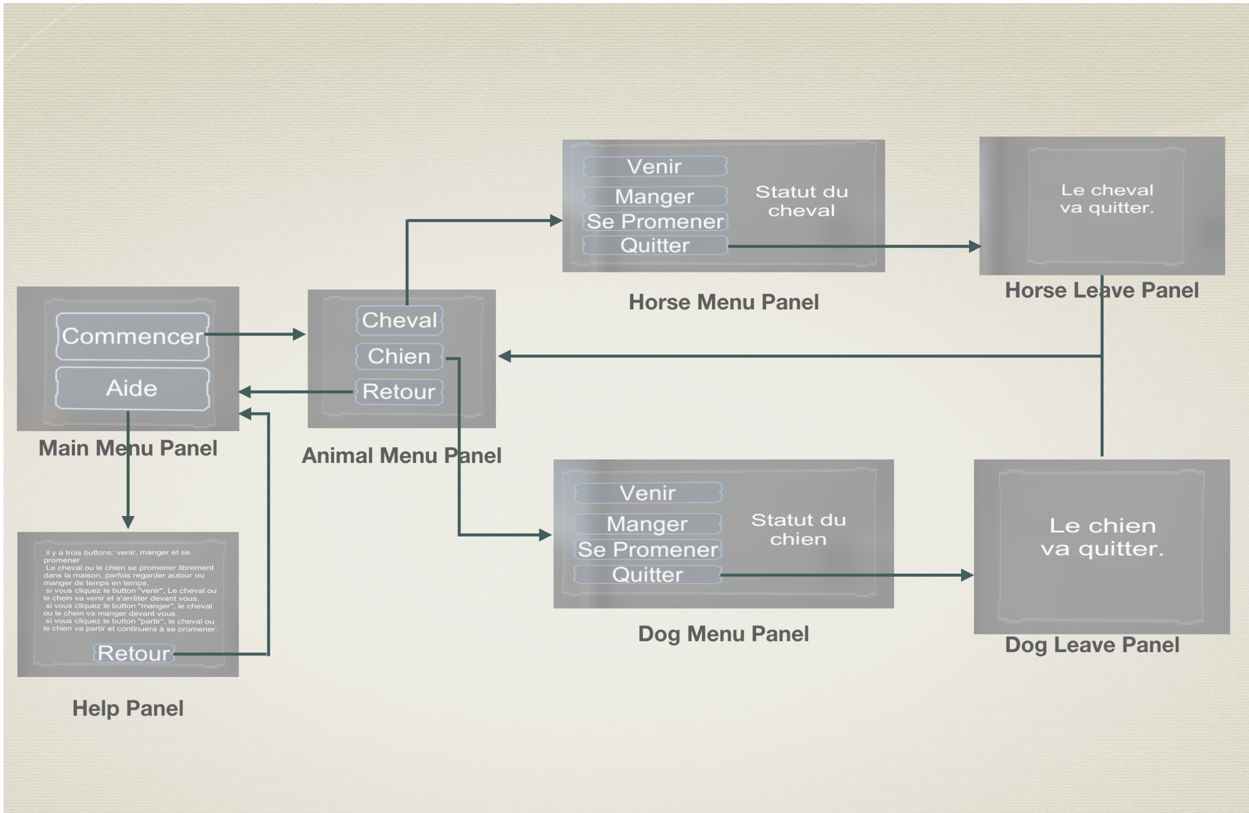


Fig. 2.14. Menu Panels with Buttons

As shown in Figure 2.14. For Horse Menu Panel and Dog Menu Panel, when user click the Come-Button(Venir), Eat-Button (Manger) or Wander-Button (Se Promener), they don't open other panels, they just initiate an instruction function who was defined in animals' script same like the single event called On Click happened on 2D buttons, and update the current action of the animal in the status bar next to the button. For example, when the Come-Button is triggered, the ComeHere Function in the animals' script is called and "The horse is coming" is indicated on the screen. The Leave Panel without button means that the animal leaves the room, after animal leaving, the Panel returns to the Animal Menu Panel.

Finally, we need to update the Input System, 2D buttons are selected with the mouse, but how to select and click buttons in 3D environment. Here we added an invisible Collider Component of its own size to all the buttons on the panels, and tag each button as "Button", then add a radium ray from the center of the camera's screen view on the 3D capsule. As the user turns the head, the camera's screen view follows and the radium follows. When the radium cursor touches the 3D object which is tagged as "Button", the button changes color. At this moment, clicking the space key on your keyboard or Handle (controller) key can select the Button. When VR headset is used, there is a blue dot in the center of the field of vision, which is the launching point of the radium ray. In other words, when the point is pointed at a button and button's color is deepened, press the handle (controller) key can select the Button (Figure 2.15).

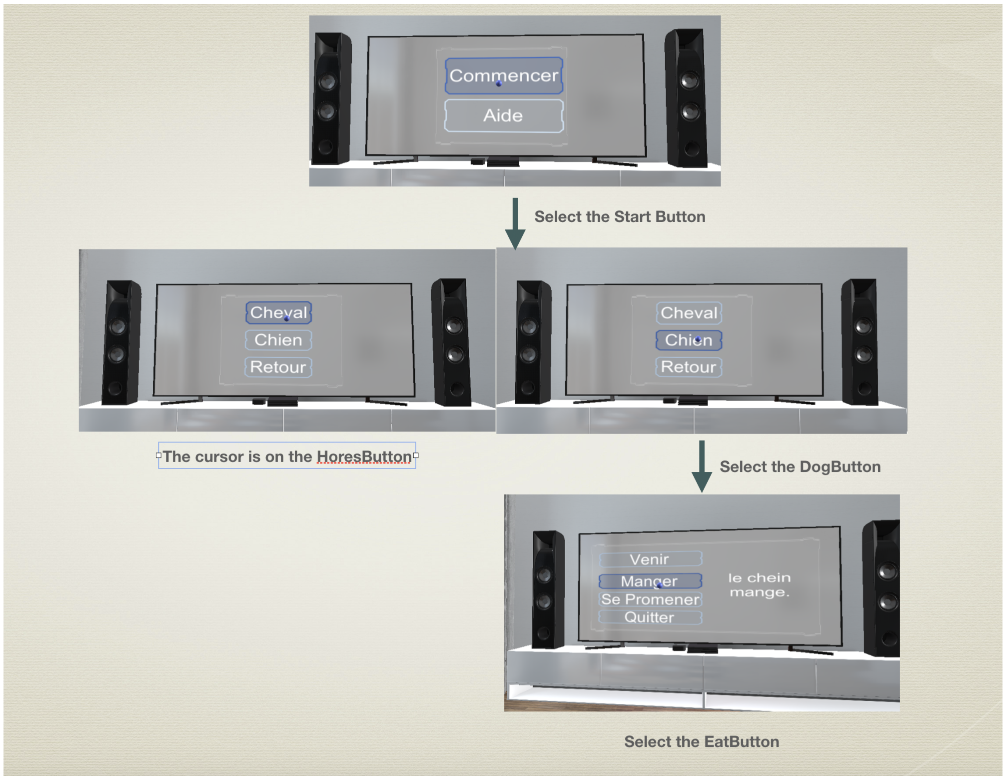


Fig. 2.15. Ray cursor selection

Now we can complete interaction by selecting the Button in the 3D environment. Next, we will replace the visible Button with the speech recognition system to complete the interaction. In addition, in non-subjective interactions, the Neurofeedback system will indirectly intervene in users' emotions through interaction. Whether it's 2D Button, 3D Button, speech recognition or Neurofeedback, the nature of an animal's execution of an instruction is to call different instruction functions. But the system that sends instructions is different.

2.6.3. Speech instruction system

As a method for users to actively interact with animals, speech instruction system can accept users' verbal interaction with animals. With the addition of speech instruction systems, Zoo Therapy is going to be even more lively. Imagining when you call a horse, it will run up to you. If you ask him if he wants to eat something, he will come and eat in front of you without hesitation. Even in real life, a horse that knows you doesn't always answer immediately to every call. This satisfaction of being responded to in a timely manner can be well experienced by the user when using voice interactions.

We will directly use the ASR model that is now commonly used for speech recognition, and then combine the trained model with Zoo Therapy through some methods. In order to adapt to our project, all the audio data of the training model were recorded by the author and her classmates. The architecture of the model, the results of training, and how to integrate with Zoo Therapy will be presented in Section 3.1.

2.6.4. NeuroFeedback system

As a non-subjective interaction, it is also a very important try of interaction in our project, namely the Neurofeedback system. The system stimulate user's positive emotions by increasing or decreasing the animal's interaction with the user. This interaction is conducted in an invisible way, and contributes to the elimination of anxiety, frustration, depression and other negative emotions, and promotes the motivation. We used the Emotiv Epoc EEG headset to track users' emotions, then observed the individual trend of each emotion value over a period of time according to the real-time monitored emotions, and provided the interactive instructions (rule-based method), or provided the interactive instructions according to the general trend of integrated emotions, with the help of the reinforcement learning model. The design and implementation of Neurofeedback system, the rules of rule-based method, the design and training of reinforcement learning model and the results will be explained in details in Section 3.2.

2.7. Modules integration for Zoo Therapy

In this part, we will explain how to connect the five functional modules in some specific ways to form the final version of Zoo Therapy. We've described in details what the five functional modules in Zoo Therapy are, and how they work, let's look at how they're pieced together.

In Unity, we first import Scene Module, and Zoo Therapy has the 3D room. Next, we import Animals Module and Sound Module. We have the 3D room and two 3D animals that can move and bark. The import of the Animals Module gives us animals' script. At this point, in order to limit the activity of the animal on the Scene Module scope, we added Map Module in the animals' script. The location, scope of activities, and mode of movement of the animal are referenced by the Map Module. Finally, the Human-Computer Interaction Module is added to the animal's script. Every action in 3D environment is updated frame by frame by an 'update' function. This Function will be called in every frame and it will monitor whether there is a new instruction in real-time. If there is no instruction, Unity will execute the current script command to update the location of the animal. If there is, it will immediately call the new instruction's function, complete the new instruction task. In this way, the receiving instructions cooperate with the animal's actions, sounds and movement will present the final Zoo Therapy seen by the user.

The Figure 2.16 shows the flow-chart of Zoo Therapy. The "Start" in the middle of the figure indicates that users put on VR headset and Start to use Zoo Therapy. First, the user takes seat on a sofa and get a 360-degree view of the entire environment. On the left hand side they can see the French Windows and the outdoor garden, on the right hand side is the kitchen and the room's door, the dining room is in sofa's back and in front of the user is the TV. The TV's screen provides the instruction menu to the users. At first, they can choose an animal of their liking. After selecting a animal, the animal will enter the room through the auto-door. The default state of the two animals is Wander mode. At this point, user can issue instruction to the animal at any time, by speaking to the animals, or by emotional value changes recorded by the Neurofeedback system, which will trigger corresponding instruction functions in animals' scripts, which specify the Audio Clips and Animation Clips to be played in the next frame, and calculate and generate paths. Users will see a lifelike animal interacting with them, the animal's barking are matched by its actions, and the sound of walking accompanies the animal's steps. Here, the synchronization of sound and animation is completed by manual adjustment, without any frame dislocation or delay, so as to have a sense of reality in VR equipment. The Map Module sends the animals to the specified interaction position. After the interaction, the animal either continues to Wander mode or switches over to other commands. Once the Leave function is triggered, the TV screen will ask the user to change animals or end the therapy session.

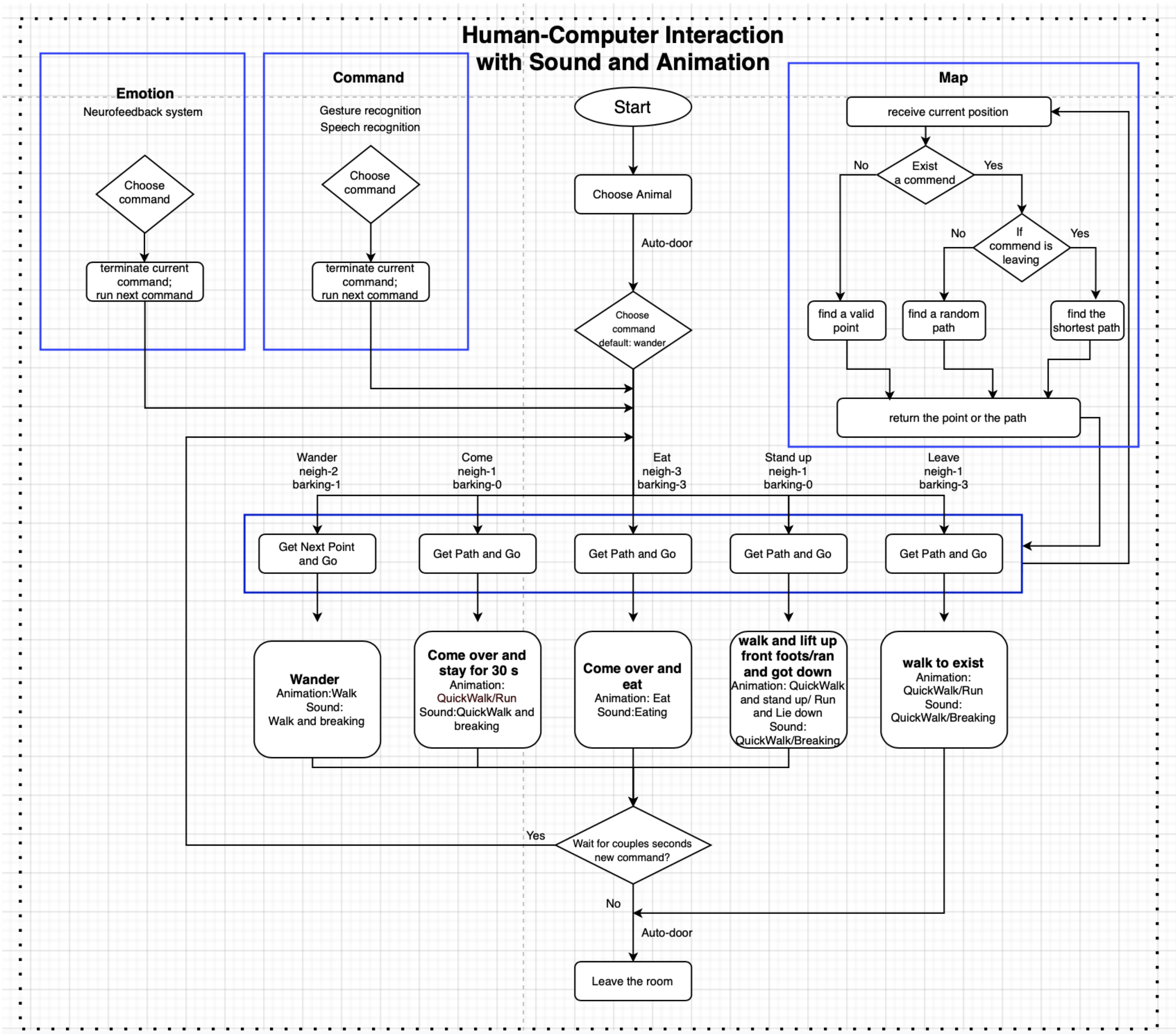


Fig. 2.16. Flow Chart for Integrate Function Module

Chapter 3

Interactive system and learning model

In Chapter 1, we mentioned that in traditional AAT, the interaction between the user and the animal can produce a strong emotional connection, and the therapeutic effect of AAT depends on the strength of this emotional interaction. In other words, the interaction between humans and animals can reduce the arterial blood pressure of the heart and respiratory rate by affecting the secretion of user hormones. The emotions, mental impulses, and games used in AAT can cause psychosomatic effects[**15**].

Then when using virtual animals to complete AAT, the way of interaction becomes particularly important. In most human-computer interaction applications, it is most common to select interactive behaviors through user interface menus. For example, the user needs to click the option in the menu on the Table screen or click the menu option through the computer mouse or VR controller. However, it may be difficult for some users to master the hardware. Moreover, this interaction is issued by the user in a single direction to the virtual animal, the virtual animal just waits for the instruction and completes, and the user's emotions will not affect the behavior of the virtual animal. This is very different from real animals. In reality, animals usually proactively probe or stay away from the user, forming a bidirectional interaction between the user and the animal.

Therefore, to establish a more direct and convenient bi-direction emotional interactions between the user and the virtual animal, we retain the menu panel interaction method while adding two additional interaction methods, the speech instruction system, and the Neurofeedback system. The three methods provide a more comprehensive interactive experience for Zoo therapy. The three interaction methods can be divided into two parts: subjective interaction and non-subjective interaction. Subjective interaction refers to the interactive instructions **actively issued by the user** and includes **Menu Panel and Speech Instruction system**. Non-subjective interaction is the interaction that the **Neurofeedback system** that guides the animal to actively interact with the user **based on the user's real-time emotions**. As shown in the Figure 3.1.

The three interaction methods are complementary. The menu panel can provide a click-and-interactive game feel, and it is also an alternate interaction option for users who do not want (or not can) use speech instruction. The speech instruction system provides a more direct interaction way than the menu panel, and for some users who are inconvenient to use hardware devices to participate in the interaction, this method is simpler and more convenient. When the user interacts subjectively in the above two ways, it means that the virtual animal in Zoo Therapy has aroused the user's interest in active interaction, so the intervention effect of the Neurofeedback system may not be obvious. However, if a user does not actively interact with the virtual animal, the Neurofeedback system will still guide the animal to actively interact with the user because of the user's emotional changes. Throughout the use process, the three interaction methods work together to maximize the interaction effect.

About the Menu panel method, we gave a specific explanation in Section 2.6.2. In VR Zoo Therapy, users can use the VR handle or controller to select and click the 3D button in the menu above the panel to complete the interaction. Figure 2.14 indicates the menu on each panel, the 3D buttons contained in each menu, and the switching relationship between panels. Figure 2.15 shows the screens when the user uses the handle to select the interaction.

Speech instruction and Neurofeedback are the two interfaces of Zoo Therapy, which we will introduce separately in this chapter. Section 3.1 will introduce the selection of speech recognition model, data generation, model training and evaluation, algorithms for filtering instructions, and Pilot experiment after being joined into Zoo therapy. Section 3.2 introduces the feedback rules of the rule-based method in Neurofeedback systems and their limitations. Finally, the Neurofeedback system improved by the reinforcement learning method will be introduced.

3.1. Speech instruction system

3.1.1. Objective

In Ferreira's project [18] mentioned in chapter 1, there is a pilot research. Its purpose is to choose an AD patient's most acceptable and favorite interactive method from the five different interactive technologies (HTC VIVE (VR), PC with the mouse, Tablet, AR, and the Leap Motion Controller). Among them, the interactive mode of VR with the controller is not liked. The reason is that some participants with cognitive impairment do not understand how to use the buttons on the controller. To avoid similar problems in Zoo Therapy, and also to enrich our interaction methods, we offer one more interaction option. We have added

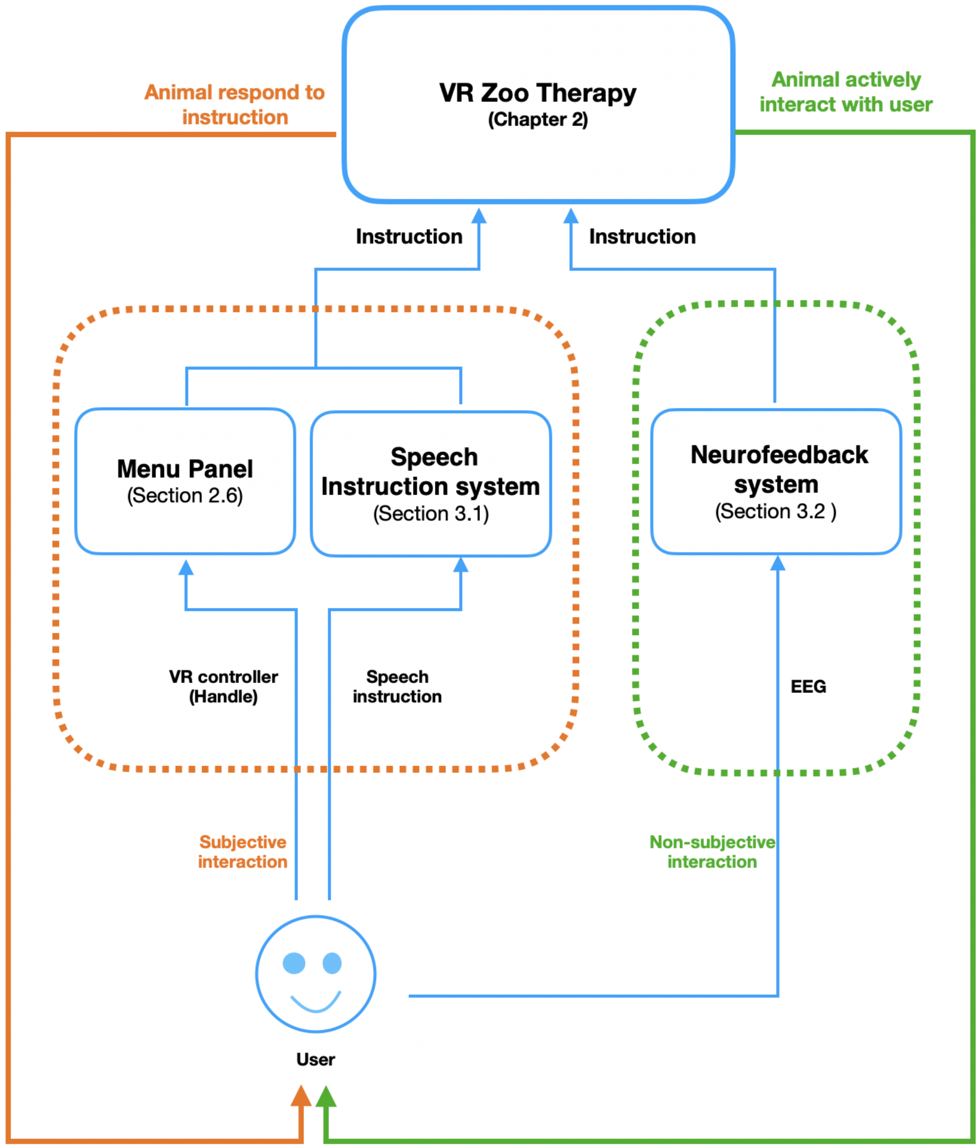


Fig. 3.1. Interaction flow chart of Zoo Therapy

a **speech instruction system**. This allows users to interact with virtual animals more directly using some words without having to master the intermediate hardware devices.

The goal of this speech instruction system is trying to interact with virtual animals in the environment through the voice of participants to recognize the text content of the user's voice through the trained model, and then issue instructions to the animal.

For the interaction of virtual animals in Zoo Therapy, there are only 4 commands that participants can issue (**come, walk, eat and leave**). So, the speech instruction model does not need to "understand" everything in the user's voice, it only needs to be sensitive to words that may involve instructions. We will train a Speech Recognition model that understands these four instructions.

3.1.2. Speech recognition

3.1.2.1. End-to-End ASR model

Automatic Speech Recognition (ASR) is a method that converts spoken language into text. Speech recognition can be generally divided into "traditional" speech recognition and "End-to-End" speech recognition[**31, 58**]. The traditional speech recognition model is very complex, like all HMM-based model approaches that require separate components and training for the pronunciation, acoustic and language model. End-to-End models jointly learn all the components of the speech recognizer by a neural network. This is preferable since it simplifies the training and deployment process.

The mainstream ASR models are using End-to-End deep learning model [**61, 62, 64, 30**]. We directly selected an open-source code base [**60**] End-to-End ASR (Transformer[**56**]) model which accepts a spectrogram parsed from the user's voices as the input and the output is text.

The architecture of our ASR Transformer is shown in Figure 3.2, which stacks multi-head attention and position-wise feed forward neural network with convolutional neural network for both the encoder and decoder. The encoder is a stack of N = 3 identical layers. Each layer has two sublayers. The first is a multi-head attention, and the second is a position-wise feed forward with convolutional neural network. Residual connections are employed around each of the two sublayers, followed by a layer normalization. The decoder is similar to the encoder except inserting a third sublayer to perform a multi-head attention over the output of the encoder stack. To prevent leftward information flow and preserve the auto-regressive property in the decoder, the self-attention sublayers in the decoder mask out all values corresponding to illegal connections. In addition, positional encodings [**56**] are added to the input at the bottoms of these encoder and decoder stacks, which inject some information about the relative or absolute position in the sequence to make use of the order of the sequence.

3.1.2.2. Generating data and label

As mentioned earlier, this speech instruction model does not need to perfectly recognize all the user's voices into text. In order to save training time, shorten the development cycle, and achieve the purpose of interaction, we didn't choose to use the usual large speech recognition training set. Our goal is to make the virtual animal "understand" the user's instructions, so the model will be trained to recognize specific instruction words. For the four subjective interactive commands of Zoo Therapy, we wrote some texts

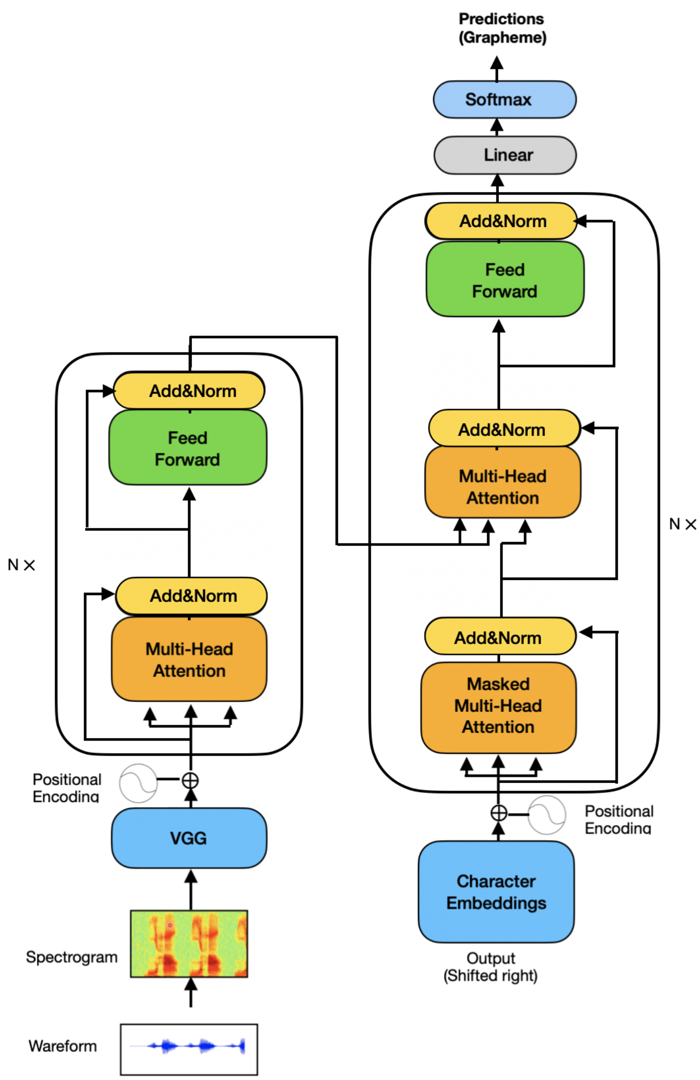


Fig. 3.2. Our ASR Transformer architecture.

containing commands as labels, and recorded voice clips corresponding to the text labels as input, and generated the training materials of Zoo Therapy in this corresponding way.

First of all, for the four interactive instructions, they can actually be divided into letting animals approach, go away or eat. We wrote 40 texts. Each text contains a sentence that may involve instructions such as:

- Text 1: Hello, horse, come here.
- Text 2: Come to me.
- Text 3: Would you like to come over.
- Text 4: Eat apple?
- Text 5: Go ahead.

- Text 6: Go away.
- Text 7: Walk around
- Text 8: Go out
- ... ...

Next, in order to make the model adapt to different voices, a male and a female completed the recording. Each person reads the text content one by one and generates 3-second audio clip. After the recording is completed, the audio and the text correspond to each other as the training data. Among the 80 data, 40 are about instruction "come", 25 are about "walk" or "go", and 15 are about "eat".

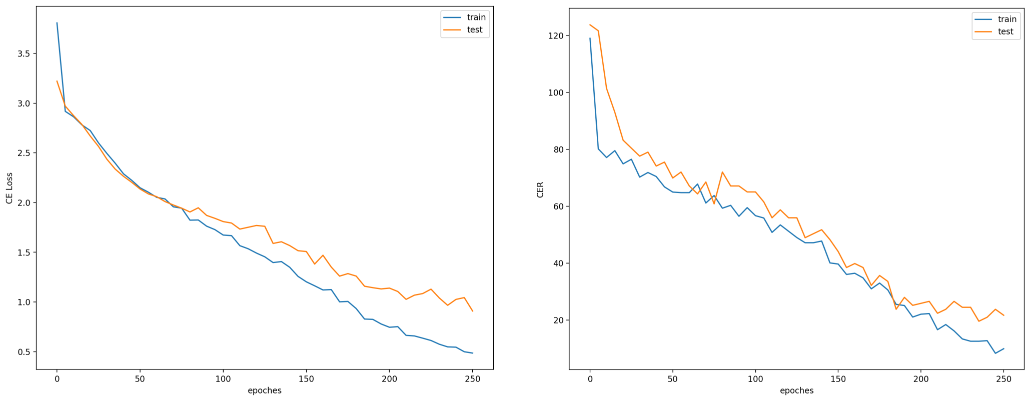
3.1.2.3. Experiments: training and evaluation

The statistics of 80 data is shown in Table 3.1. We apply the stratified splitting with 75% data as training data, and 25% data as test data.

Table 3.1. Data distribution

	Total 80	Training set 60	Test set 20
come	40	34	6
walk or go	25	18	7
eat	15	8	7

The model runs 250 epochs with learning rate = 3e-4, dropout-ratio = 0.1, batch size = 20, epochs = 250, optimization = Adam. The CE loss on the training set is from 3.8069 to 0.5089, on the test set is from 3.2210 to 0.9097. The Figure 3.3(a) shows the learning curve and the blue line represents the change in CE loss in the training set, and the orange line represents the change in CE loss in the test set. The Character Error Rate (CER) on the training set is from 119.03% to 10.53%, on the test set is from 123.78% to 21.68%, shown as Figure 3.3(b).



(a) CE loss curve

(b) CER curve

Fig. 3.3. Zoo Therapy speech command model learning curve

We take the model with the smallest test loss, as it has the best generalization performance, and used it to make predictions for the user's voice content. The predicted content will further be determining whether it contains instructions for interacting with virtual animals.

3.1.3. Integrate with Zoo Therapy

After getting a piece of text predicted from the trained model, the speech instruction system needs to determine whether the prediction text contains any instruction using a determination-instruction script. The script is to determine whether prediction text contains words related to the instruction that we call sensitive words, shown in the Table 3.2. When a sensitive word appears, its corresponding command will be sent to Unity.

Table 3.2. Different sensitive words to horse's actions

Commands	Sensitive words
come	come, here, hello
eat	eat, apple
walk around	walk, go

When testing the model, we found that the word beginning of the predicted content is often correct. For example, the voice content is "horse, come here" and the predicted text is "horss come here". Or the voice content is "come" and the predicted text may be "comu" or "coom". So we first determine whether there exists the initial letter of a sensitive word in the predictive text, and then extract the initial letter and the following N characters. The length of N is the same as the length of the sensitive word. Next, the edit distance between the extracted characters and the sensitive word is calculated. When the edit distance is less than $\lceil \frac{N}{3} \rceil$, we think that the text contains sensitive words and can send corresponding instructions. Sensitive words with the same initial letter will be judged in the order of N from small to large.

Let us illustrate with an example. We use still the voice content as "horse, come here", and the predicted text is "horss come here". The determination-instruction script searches from the first character "h" in the predicted text. Two sensitive words are starting with "h": "here", the length N is 4. "hello" 's length N is 5. Firstly, 4 characters after "h"(including "h") are extracted, it gets "hors". The edit distance between "hors" and "here" is 2 which is not smaller than $\lceil\frac{4}{3}\rceil$. So there is no word that can generate instructions. Continue to extract the words "horss" and "hello" with N=5 and then calculate the edit distance. The result is 4, which is greater than $\lceil\frac{5}{3}\rceil$. Next, the letter "c" was found, the length of the sensitive word "come" was 4, extract the 4 characters after "c", it gets "come". And the edit distance between "come" and "come" was 0, it's smaller than $\lceil\frac{4}{3}\rceil$. The sensitive word "come" corresponds to the command "come". At this time, the determination-instruction script will send instruction "come" to Unity to trigger the interaction of the virtual animal.

The edit distance we use here is a way of quantifying how dissimilar two strings (e.g., words) are to one another by counting the minimum number of operations required to transform one string into the other. Different definitions of an edit distance use different sets of string operations. We used the classic edit distance algorithm, Levenshtein distance(Algorithm 2).

As shown in Table 3.3, use Algorithm 2 to calculate the edit distance between "come" and "comu". Each number represents the edit distance between the two words corresponding to the row and column where the number is located. Then the 1 in the bottom right corner is the edit distance between "come" and "comu". Since 1 is less than $\lceil\frac{4}{3}\rceil$, the determination-instruction script will send the "come" instruction to Zoo Therapy.

Table 3.3. Edit Distance between"comu" and "come"

	C	**O**	**M**	**U**
C	0	1	2	3
O	1	0	2	3
M	2	1	0	1
E	3	2	1	1

After completing the determination-instruction script, we integrate it with the speech recognition model and Unity. When the user starts to use Zoo Therapy, Unity turns on the microphone to record audio at a sampling rate of 16khz. It generates a waveform audio file every 3 seconds and store it locally and sends the audio storage path to the trained speech recognition model. Once the model receives the storage path, it recognizes the audio

Algorithm 2 Edit Distance

Initialization
D(i , 0) = i
D(0 , j) = j
for each i = 1,2, ... M **do**
  for each j = 1,2, ... N **do**

$$D(i,j) = min \begin{cases} D(i-1,j)+1 \\ D(i,j-1)+1 \\ D(i-1,j-1)+\begin{cases} 1, & \text{if} x(i) \neq y(j); \\ 0, & \text{if} x(i) = y(j). \end{cases} \end{cases}$$

  end for
end for
D(N,M) is distance

and obtains the predicted text. Finally, the determination-instruction script determines whether the text contains the instruction content and sends the instruction back to Unity. We conducted a preliminary experiment on Zoo Therapy with speech instruction system and introduce it in the next section.

3.1.4. Pilot experiment

The two purposes of the tests are to know:
(1) Is it possible that users interact with virtual animals through their voice commands?
(2) What impact will the interactive system in Zoo Therapy have on users?

3.1.4.1. Experimental process

Participants:
Five participants of different ages, genders, and accents participated in the test. As shown in the Table 3.4.

Table 3.4. The situation of the five participants

Participants	**Age**	**Gender**	**Language**
participant_01	33	F	Chinese
participant_02	35	M	English,Mandarin
participant_03	4	F	French, Mandarin
participant_04	27	M	Hindi,English
participant_05	38	F	Chinese

Process of Experiment:
The experiment includes two parts. The whole process is 5 to 10 minutes.

In the first part, participants use the mouse to interact with virtual animals through the 3D menu (Figure 2.14) in Zoo Therapy. They can choose a horse or a dog, and then they experience letting animal approach, eat, and leave.

In the second part of the experiment, we told the participants that they can interact with the animal by talking to them. Animals can come over, eat, walk or leave. The user then chooses whether to interact with the animal through voice or continue to use the 3D buttons on menu panel. We didn't specifically explain which words correspond to instructions, because we wanted to observe what kind of command words users will send to animals. If we don't have them in our sensitive vocabulary, we can add them to train our speech recognition model in the future.

After the experience, we asked the user's overall sense, the impact of different interaction methods on the user, suggestions for improvement, and let users make subjective rating for Zoo Therapy including speech instruction system.

3.1.4.2. Results

1. Is it possible to interact with virtual animals through speech instruction?

Table 3.5 "Speech interaction (0/1) " indicates whether the participant can interact with the virtual animal through their voices, 0 means no, 1 means yes.

The table shows all 5 participants can interact with the virtual horse through their voices.

Table 3.5. The Evaluation of the five participants

Participants	**P_01**	**P_02**	**P_03**	**P_04**	**P_05**
Menu panel interaction (0/1)	1	1	1	1	1
Speech instruction interaction (0/1)	1	1	1	1	1
Interaction method preference (B/S)	S	S	B & S	S	S
Evaluation	5	7	10	8	4

2. What impact will the interactive system in Zoo Therapy have on users?

We asked 5 participants about the overall experience of Zoo Therapy and the experience of using two different interactive methods. All 5 participants said that the speech interaction method brought surprises to people. Although the virtual horse is in the computer, compared with a mouse click in 3D buttons on menu panels, the animal's direct response to the participant's voice is still delightful. The participants expressed that they prefer such animals and want to continue to interact with them.

Participants 1 felt that the speech interaction method was more interesting than the 3D buttons on menu panel interaction method. She did not expect that the horse would respond to her call. When the horse responds with a neigh and runs to the participant, she felt very happy and made her mistakenly believe that the real horse is interacting with them.

Participant 2 said that he liked the horse very much. In the first stage of use (with 3D buttons on menu panel), he only felt that this was an ordinary interactive game. Although the graphics were exquisite, it was no surprise compared to other products. He understood that when he clicks "come" with the mouse, the animal will approach. The "leave" button will cause the animal to leave. When he came to the second part of with the speech interaction, the participant expressed his excitement. He thought it was amazing and asked why the animal understood what he was calling it. This feeling was very peculiar. Although the participant has been told in advance that the animal will come to the participant by saying "come", he is still very happy when he saw the animal coming.

Participant 3 is a child, and she liked that virtual animal very much and felt that it is no different from the animals in the zoo.

Participant 4 said that the experience of speech interaction is completely different from that of buttons. It makes people feel that this is a real horse, not a virtual animal.

Participant 5 is a machine learning engineer. The participant understood the speech recognition model and training principles. But after the experience, she said that when the animal responded, she would not think of the theory behind it. She just felt that the animal is interacting with her and felt very special.

Participants rated the Zoo Therapy with speech command system from 0-10 subjectively in the "Evaluation" based on their own experience, as shown in the Table 3.5. The table also shows whether the participants interact with the virtual animal through Menu panel interation or speech instruction interaction. "Interaction method preference (B/S)" gives which interaction method prefers by each participant, where "B" stands for 3D button on menu panel and "S" stands for speech instruction.

Even in a non-virtual reality environment, the five participants clearly expressed their excitement and delight with the animal's response. This makes us believe that in VR settings, users will have a more realistic and positive experience.

3.1.4.3. Finding and further work

The overall feelings given by the 5 participants were positive. But there are still some shortcomings in the use process.

In terms of models, the amount of data to train the model is relatively small, and it cannot cover all vocabulary related to instructions. The current model can only act on positive instructions. For example, when the user says "come here", the speech instruction system will issue a "come" command. If the voice content is "Don't come", the system will still issue a "come" command. For humans, these are two opposing instructions, but the speech recognition model now only recognizes the word "come". For the model, "don't come" will recognize like "*** come". If we want the speech recognition model to be able to distinguish negative sentences, special training data is required for retraining in the next stage of development. At this stage, to avoid the interaction not complete, we will tell users don't use negative sentences to communicate with animals.

Moreover, when we generate a wave document in 3 seconds, the user's voice will be cut off. If there is a sensitive word at the disconnection, the system will miss the command. In the next improvement, we will try to extend the recording time, or set the voice command switch to improve this situation.

During the experiment, because we are using a CPU processor, the processing speed is slow, and the prediction time of each voice is about 5-10 seconds, and there will be a problem of instruction delay. Although the participants indicated that the slow reaction time of the animal is acceptable, the faster reaction time brings a better feeling of use. We will use a GPU processor to participate in training and experimentation in the later improvement.

For further, when AD patients will participate in the experience, we may expand the amount of data and retrain the model according to their language habits.

3.2. Neurofeedback system

3.2.1. Objectives

To be different from the traditional virtual animal passively waiting for instructions and support the bi-direction interactions between the virtual animal and the participants in Zoo Therapy, and to reduce the negative emotions of the participants timely, we created the Neurofeedback system. The system guides the animals interact with the user according to user's changes of EEG emotional values in real-time. So, it gives virtual animals the ability to perceive the user.

3.2.2. Rule-based Neurofeedback system

To achieve this goal, we created a rule-based agent, the core of the Neurofeedback system. We formulated rules based on common sense. It uses Emotiv electroencephalogram (EEG) headsets to detect participants' emotions in real-time and according to the feedback rules, the system gives instructions to the animals. The changes in animal behavior will stimulate emotional changes in participants.

Zoo therapy uses **four emotions** values generated through EEG, namely frustration, engagement, excitement, and valence.

- Frustration: In psychology, frustration is a common emotional response to opposition, related to anger, annoyance and disappointment. Frustration arises from the perceived resistance to the fulfillment of an individual's will or goal and is likely to increase when a will or goal is denied or blocked[**17, 12, 19**]. In our projects, for example, when the user wants to have a horse or a dog be in front of him, but the animal doesn't respond, which may lead to frustration, so we design that the animal will respond to the user's command immediately;
- Excitement: It is a feeling or situation full of activity, joy, exhilaration, or upheaval. It's kind of a positive emotion, and when people are excited to do something, then general engagement is higher;
- Engagement: It involves interest, boredom, happiness, anxiety, and other affective states, any of which factors could affect the user's involvement. We want our customers to have as much engagement as possible with Zoo Therapy;
- Valence: The value associated with a stimulus as expressed on a continuum from pleasant to unpleasant or from attractive to aversive. In factor analysis and multidimensional scaling studies, emotional valence is one of two axes (or dimensions) on which an emotion can be located, the other axis being arousal (expressed as a continuum from high to low). For example, happiness is typically characterized by pleasant valence and relatively high arousal, whereas sadness or depression is typically characterized by unpleasant valence and relatively low arousal.

Frustration among these four emotions is a negative emotion, and the other three emotions are all positive emotions. The agent will send instruction when negative emotion increase, or positive emotions decrease. So how does the agent give instructions when the four emotional values change at the same time? The rule-based method gives instructions based on the change in a single emotional value at one time.

3.2.2.1. Feedback rules

For each emotion, the agent calculates the mean of the emotion values for every 15 seconds and then calculates the rate of change with the previous 15-second's mean of the emotion values. The emotion that changes the fastest is considered to be the emotion that should be corrected. Then, the agent sends instructions according to the rules that regulate this emotional change. The rules are as follows:

- If the frustration rises the fastest, the agent will decide to end the current Zoo Therapy session and the animal leaves the room.
- If the excitation drops the fastest, the agent instructs the animal to do a different action such as stand up, or ask the dog to lie down in front of the user to stimulate the user's excitement.
- If engagement or valence decrease fastest, the agent will let animal be close to the user to attract user's attention to improve engagement. If the user's emotional value have an improvement, the animal will stay indoors doing actions as instructed by the agent. If there is no improvement, we consider that the animal behaviour does not improve the user's emotions, and the agent will ask animal to leave the room and the therapy session ends.

3.2.2.2. Limitations of rule-based Neurofeedback system

The agent under the rule-based method follows the human-made rules to give feedback. As long as the emotion value meets the rule conditions, the agent will issue instructions. Therefore, the quality of the agent's feedback directly depends on the quality of human-made rules. Human emotions are diversified and complex. Even when people face-to-face, it is difficult to guess other people's moods and thoughts. So for participants who have never seen it before, our rules are likely to fail to stimulate their emotions because different users may have different feelings about the same action of animal, which will lead to high variance of the rules. The rule-based feedback system has two main drawbacks.

1. Emotional bias that triggers feedback

We use four emotions, but the rule-based method agent gives instruction only depending on one single emotion, does not consider the influence of other emotions. However, these four emotions do not exist independently. In other words, it is not when frustration rises the fastest, other emotions do not exist, but we did not consider them. For example, when the user's frustration increase, sometimes the engagement may also increase. Even if the user is frustrated, he wants to participate in the game. But according to the rule, the animal will leave the room when the user's frustration increases fastest, and the game is over. Then the impact of this instruction on the user is likely to be negative. So, can the agent consider other emotional changes when the frustration value rises? How to improve the agent to take into account the influence of multiple emotions?

In addition, if frustration rises, should the rule be that animals go to the user, or something else. This is the second deficiency of the rule-based method, how to formulate rules rationally and minimize the gap between user expectations and our instructions.

2. Feedback deviation

The formulation of artificial rules is based on some assumptions. For example, researchers believe that the animal's departure can reduce the user's frustration value, and the animal's approach can increase excitement or participation. Such rules can indeed effectively improve emotions for some users. But some users may be the opposite. How to make the rules flexibly adapt to more users?

Based on these limitations and ideas, we considered developing a more intelligent agent that can flexibly give the most reasonable feedback instructions under the action of multiple emotional values. The agent needs to learn a set of feedback rules, under the situation that we don't have standard rule information. We choose reinforcement learning model to improve this rule-based Neurofeedback system, called RL-based Neurofeedback system

3.2.3. Improving Neurofeedback system using reinforcement learning

To improve the limitations of the rule-based method, we designed a reinforcement learning model as the agent for our Neurofeedback system. The agent can automatically learn how to give suitable instructions to affect the user's emotions according to the user's multiple emotional values.

3.2.3.1. Reinforcement learning (RL) model: background

Reinforcement learning (RL) is a hot topic in machine learning. It differs from supervised learning in the sense that it does not require supervised signals, and it does not require sub-optimal actions to be explicitly corrected. Instead the focus is on finding a balance between exploration (of uncharted territory) and exploitation (of current knowledge). Reinforcement learning emphasizes how to act based on the environment in order to maximize the expected benefits. It is inspired by behaviorism in psychology, that is, how an organism, stimulated by environmental rewards or punishments, gradually forms the expectation of the stimulus and produces the habitual behavior that can obtain the maximum benefit. An agent must exploit existing experience to gain benefits, as well as explore unobserved status so that it can make better choices.

RL model has three basic components: **agent**, **environment** and **reward function**. The agent is the decision-maker in the model. The medium of agent interaction is called environment. How well the agent is doing at one-time step is reward. The agent usually contains a policy represented by π, which is parameterized by a neural network, with parameter θ.

The agent selects an action from the action space (in the next section, we'll detail the action space for our project), and executes the action. Then the environment gives feedback in the form of a numerical reward and presents a new state to the agent which depends on the action taken. The agent and the environment react repeatedly leading to a sequence of state, action, and reward.

For example, we have an initial state of s_1 at time step 1. The agent will get an action a_1 based on s_1 and execute it. Then we will get a reward r_1 and action a_1 will cause a new state s_2 of the environment.The agent execute action a_2 based on s_2 will get a r_2, until time step t. This process from the initial state s_1 to the end state s_t is an episode. The sequence of all states and actions in an episode is a trajectory.

$$Trajectory : \tau = \{s_1, a_1, s_2, a_2 ...... s_t, a_t\}$$

The sum of all rewards in a trajectory is the total reward of this τ:

$$R(\tau) = \sum_{t=1}^{\tau} r_t$$

We can get the the probability that this trajectory τ occurred according to the given policy π_θ

$$p_\theta(\tau) = p(s_1)p_\theta(a_1|s_1)p(s_2|s_1,a_1)p_\theta(a_2|s_2)p(s_3|s_2,a_2)...... \tag{3.2.1}$$

$$= p(s_1)\prod_{t=1}^{t} p_\theta(a_t|s_t)p(s_{t+1}|s_t,a_t) \tag{3.2.2}$$

By enumerating all the trajectory that can occur, we can calculate the expected value of $R(\tau)$ given θ. We add each reward in the trajectory to get the total reward $R(\tau)$, as the weight of the probability of trajectory τ occurred: $R(\tau)p_\theta(\tau)$, and then add all the trajectory τ to get the expected reward:

$$\overline{R}_\theta = \sum_\tau R(\tau)p_\theta(\tau) \tag{3.2.3}$$

$$= \mathbb{E}_{\tau \sim p_\theta(\tau)}[R(\tau)] \tag{3.2.4}$$

Our goal is to maximize the expected value of $R(\tau)$. By training the agent's policy neural network, we update the parameter θ to maximize this expectation.

3.2.3.2. Neurofeedback as RL problem

We will try now to implement an RL algorithm for our Zoo Therapy. The benefit of RL-based method is that it can learn the rules from user's emotion in a flexible way, especially when the artificial rules are not accurate and hard to extract. We **start by designing the three main components for Zoo Therapy**.

The **agent** will select an action from the action space given by Zoo Therapy and send it to the environment. The **environment** of this model is the virtual animals and users. User's emotion values, as the agent's goal to maximize, is the rewards. The **reward function** of this approach is defined such that if the user's emotional value increases positively, then the reward is positive and vice-versa.

The details of the state of the environment, the reward function, and action space of the agent are as follows.

(1) Environment:

The virtual animal and the user are used as the environment for interacting with the agent. The virtual animal changes its position according to the 17-point two-way graph (introduced in Section 2.5.2) that we built and generates actions according to interactive instructions. Users will be pre-divided into three types: users who love animals, users who don't like users, and nature. The user's emotional reaction to Zoo Therapy can be detected in real-time through the EEG headset. Here we use the comprehensive emotional value of the four emotions mentioned in the rule-based method, and the combination method will explain in detail in the next section (Section 3.2.3.3). The state of the environment external to the agent is given by:

$$State, s_t = (E_t^{(u)}, A_t^{(pf)}, A_t^{(pd)}, A_t^{(px)}, A_t^{(py)}, A_t^{(a)}, H) \tag{3.2.5}$$

where,

$E_t^{(u)}$ = Comprehensive emotional value of the user at time t

H = Human's type

$A_t^{(pf)}$ = The last pass point of the animal on the graph at time t.

$A_t^{(pd)}$ = The destination point of the animal on the graph at time t

$A_t^{(px)}$ = The X coordinate of the animal in 3D Zoo Therapy at time t
$A_t^{(py)}$ = The Y coordinate of the animal in 3D Zoo Therapy at time t
$A_t^{(a)}$ = The action of the animal at time t

(2) Reward function:

The reward function consists of two parts, the most important part is the comprehensive emotional value for the user, and the second part is the reward for the completion of the instruction.
Part 1:We compare the comprehensive emotional value between the current time step and the previous time step, and the value difference is taken as the reward.
Part 2: We give the system extra reward when the policy does not continuously change instructions. Let the policy realize that it is not possible to do the action continuously. Try to complete one action and then do another one. For example, after the horse receives the instruction to eat, it is better to complete the action of eating and then change to leave, walk, or other actions. In addition, because the "leave" instruction represents the end of the game. We hope that the agent can allow animals to interact with users as much as possible, and not leave the room quickly. Therefore, the behavior of animals is also given a small proportion of reward.

$$Reward, r_t = ((E_t^{(u)} - E_{t-1}^{(u)}) + A) \tag{3.2.6}$$

where,
$E_t^{(u)}$ = Comprehensive emotional value of the user at time t
$E_{t-1}^{(u)}$ = Comprehensive emotional value of the user at time $t-1$
A = Animal's action reward

(3) Agent:
At each time step t, the agent's policy will receive the state s_t and the reward r_t as input, and the output is the probability of 7 actions, which is regarded as the score of action, and then the highest score action will be executed.(Figure 3.4)

$$Action\ space = (0,1,2,3,4,5,6) \tag{3.2.7}$$

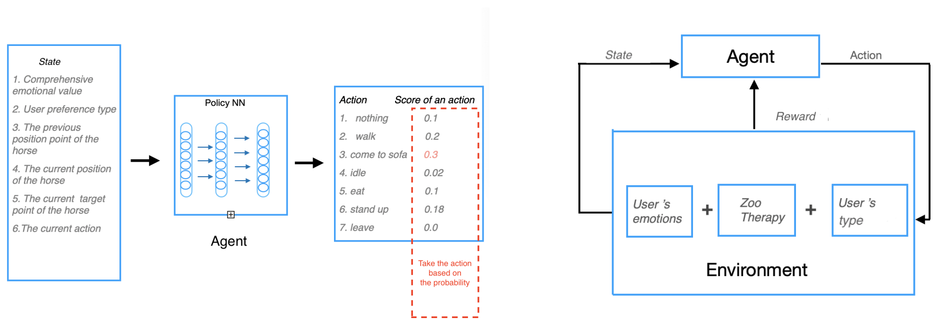
where:

0 = Nothing
1 = Walk
2 = Come to the sofa

3 = Idle
4 = Eat
5 = Stand up
6 = Leave

We adopted the open-source code base [1] of the Proximal Policy Optimization (PPO) algorithm [**52**], the default reinforcement learning algorithm in openAI, to train the model.

In the next section, we will introduce the generation of the 4 EEG emotions, and the comprehensive emotional value.



(a) The input and output of agent's policy (b) Agent interacts with the environment

Fig. 3.4. RL-based Neurofeedback agent, environment and rewards

3.2.3.3. Generating simulated EEG

In this section, we will explain how we generate EEG emotion values and make them to be comprehensive emotion value.

We get AD patients' emotion data from a similar project [**28**] in which a garden-like virtual environment is used for cognitive training, named VR Orientation Game for Cognitive Training by Manish Kumar Jha. Through his experiment, the distribution data of five emotional values of 18 AD patients in the same period were obtained. The five emotions are Frustration, Excitation, Engagement, Meditation, and Valence. We use Frustration, Excitation, Engagement, and Valence. For each emotion, three regions according to their high, middle, and low variance generates 3 distributions separately, a total of 12 distributions (Figure 3.5).

[1]https://stable-baselines.readthedocs.io/en/master/modules/ppo1.html

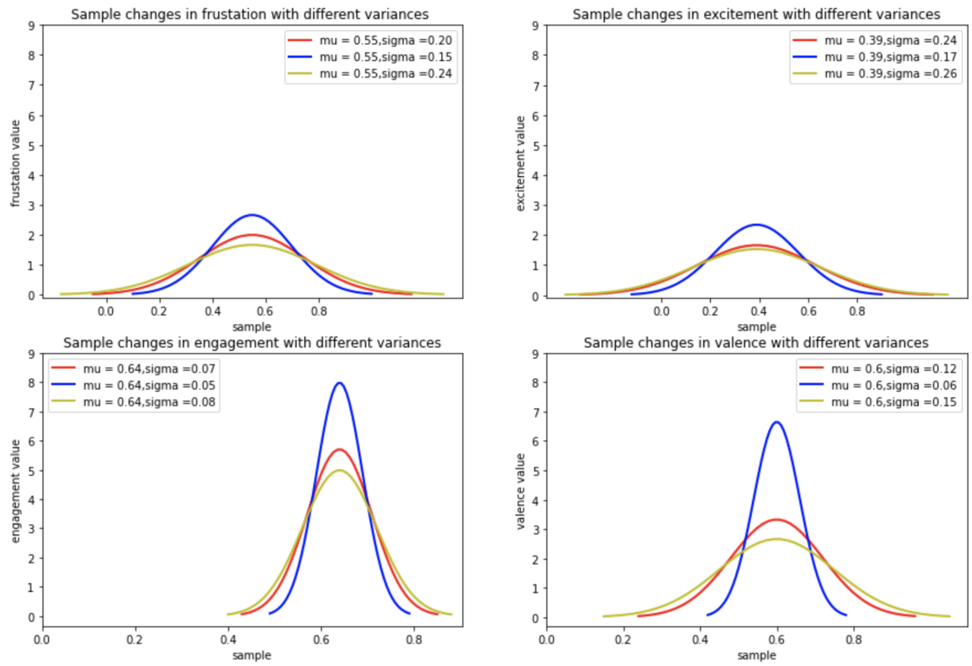


Fig. 3.5. Distributions of four emotional values

Next, we use autoencoder to encode the four emotions. Autoencoder is an unsupervised artificial neural network that learns how to efficiently encode data and how to reconstruct the data back from the encoded representation to match the original input. Traditionally, autoencoder was used for dimension reduction or important feature extraction.

Usually, autoencoders consists of 4 main parts: As shown Figure 3.6 (a)

(1) - Encoder: In which the model learns how to reduce the input dimension and obtain a compact representation.

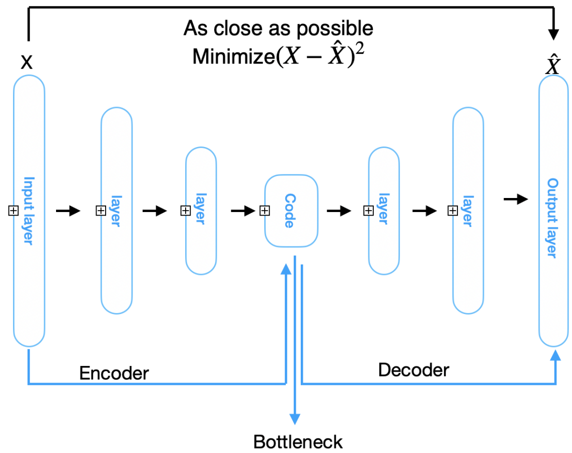
(2) - Bottleneck: Which is the layer that contains the compressed representation of the input data. We control the output dimension of encoder, i.e., the dimension of Bottleneck, and it is usually much smaller than those of the input. Thus it forces the encoder to learn a low-dimensional feature.

(3) - Decoder: In which the model learns how to reconstruct the data from the encoded representation to be as close to the original input as possible.

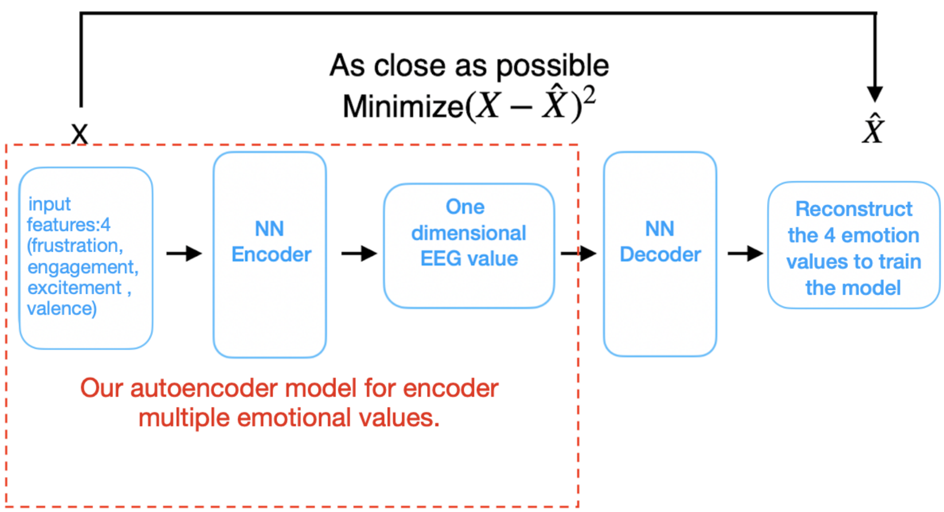
(4) - Reconstruction Loss: This is the method that measures how well the decoder is performing and how close the output is to the original input.

This network can be trained by minimizing the reconstruction error L(X,$\hat{X}$), which measures the differences between the input and the reconstructed output.

In our project, the input of the autoencoder model is a four-dimensional vector, and each component is a value randomly extracted from a distribution of each emotion we simulate.



(a) Autoencoder model structure. The purpose of Autoencoder is to make the input X and output $\hat{X}$ in the figure be as close as possible



(b) Our autoencoder model

Fig. 3.6. Autoencoder

The output of the encoder is the emotional value compressed from four-dimensions to one-dimension, while the output of the decoder is the reconstructed four-dimensional emotional value from the one-dimension value.

We tested different parameter combinations on the model. The best combination is 100 as the number of epochs, 1e-4 as the learning rate, 3 as the batch size, 10,000 as the sample number, linear as the activation function, MSE as the loss, and Adam as the optimizer. The following Figure 3.7 shows the training loss curve of the model under this set of parameters.

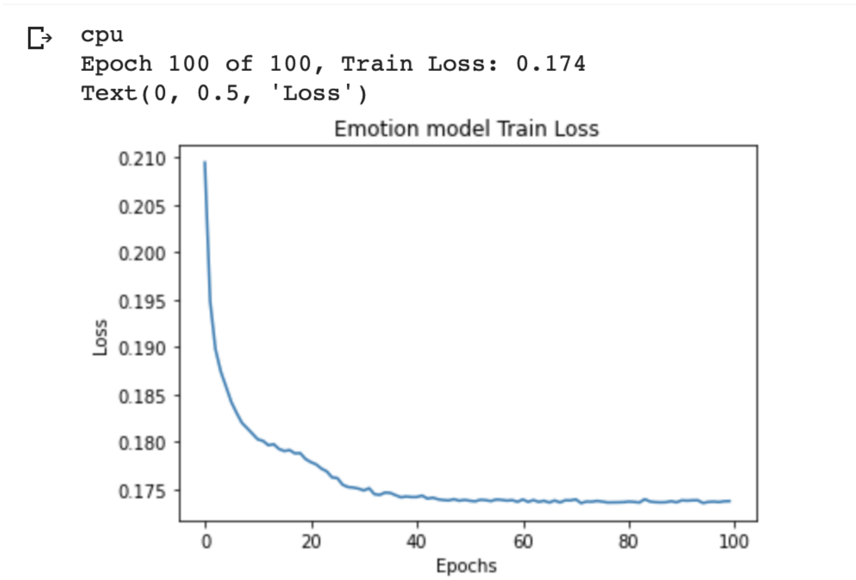


Fig. 3.7. The train loss curve of the model when epochs=100, learning rate=1e-4, batch size=3, sample number=10000, activation functions= linear, loss function = MSE and Optimizer = Adam

With the trained autoencoder model, we only take the encoder part to process a variety of emotional values Figure 3.6 (b). Then, when the reinforcement learning model is running, the encoder model will compress the current emotion at each moment and compare the current comprehensive emotional value with the comprehensive emotional value of the previous moment. The value difference will be an important part of the reward function in the reinforcement learning. You can now see the working state of the encoder using the following Figure 3.8. The x-axis is the time point, while the y-axis is the emotional values. Blue line shows Frustration, yellow line shows Excitation, green line shows Engagement, cyan line shows Valence, and red line represents the one-dimensional comprehensive emotional value extracted from the 4 emotional values at the current moment, which is the value we need.

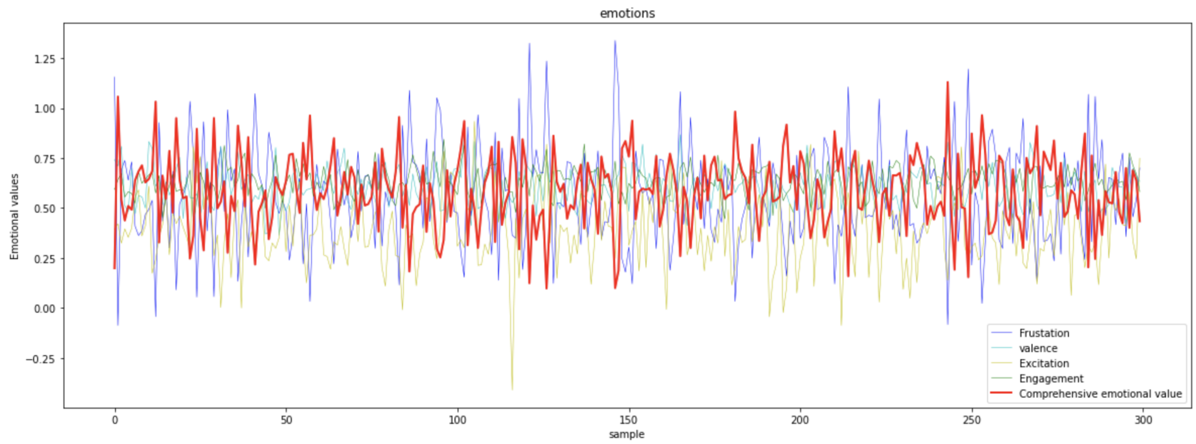


Fig. 3.8. The effect of the Encoder model is shown at a continuous point in time

3.2.3.4. Experimental framework: training and evaluation

We use the synthetic data to train the agent and simulate the experiment of the RL-based Neurofeedback system.

Our problem:

We don't know the EEG reaction of real users when using Zoo Therapy. Therefore, it is not possible to formulate feedback rules in response to this reaction. So how can the agent give more appropriate instructions to the animal? We hope that the agent can learn this rule by itself in the interaction with the user in Zoo Therapy. However, since we don't know this rule, how can we judge whether the agent has learned that rule?

Our solution:

We first **assumed** some emotional reactions of users, which can reflect the reactions of some users. There are some reasonable rules under this reaction. Next, let the agent interact with the simulated users who have these reactions in Zoo Therapy to see if the agent can learn this set of emotional feedback rules. Use this way to test the agent's ability to learn rules from the given data. Then when the data is expanded to more EEG data, the agent can learn real potential rules.

We assume that users who will use Zoo Therapy can be divided into three types: like animals, dislike animals, and nature. Different types of users have the following characteristics:

(1) Users who like animals, the proximity of animals may reduce frustration. Excitement, engagement, and valence **may** increase.

(2) Users who don't like animals may increase their frustration value when the animals are close. The other three emotions are uncertain.

(3) There is no special change in natural user emotions.

In the previous section, we have mentioned that according to the project data of Manish [**28**], we have generated three distributions with different variances of the low, medium, and high for each emotion. We call them the high-value distribution, the median-value distribution, and the low-value distribution.

We change the user's emotional reaction by sampling from different distributions and we add a distance factor to strengthen the influence of distance on emotional changes. We can see from the Figure 3.5 in Section 3.2.3.3 that there is a large amount of overlap among the three distributions of each emotion. That is to say, although emotion values sample from the high-value distribution, this has more chances of getting high value, but may not surely high value. We use this method to simulate the uncertainty of the emotion value combination.

Training:

We simulate users and create a custom gym environment to train the agent using OpenAI API. The training environment and some parameters are as follows:

(1) The observation space of the environment = State Equation (3.2.5) in Section 3.2.3.2
(2) The action space of the environment = Action space Equation (3.2.7) in Section 3.2.3.2
(3) The rewards function = Rewards Equation (3.2.6) in Section 3.2.3.2
(4) The agent's policy = MLP NN
(5) Learning rate = 3e-4
(6) Batch size = 64
(7) Epochs = 20
(8) Discount factor Gamma = 0.99

Evaluation:

We use the trained agent to test with 100 simulated users. The purpose is to test:

1. Whether the agent can give feedback when the emotional value changes?
2. Whether the agent can learn rules from simulated user's EEG data?
3. Can RL-based agent improve rule-based agent?

Results:

From the overall results of the experiment, this model met our expectations.

1. Whether the agent can give feedback when the emotional value changes?

We randomly selected 6 simulated users' results (2 users who like animals, 2 dislike animals, 2 natural in Figure 3.10). This figure shows the instructions given by the rule-based method and the RL-based method based on real-time emotional values at the same time. In this figure, the green (user-like animal), cyan (dislike), and purple (nature) lines represent the EEG curve during this period. The X-axis presents the time step, and the Y-axis is the comprehensive emotional value.

The red markers (red circles, red squares, starts) on the line are the instructions given by the RL-based agent in real-time. The blue markers (blue circles, blue squares, blue starts) are the instructions given by the rule-based agent. The circles indicate "come" or "eat" instructions to let animals approach, the stars indicate "walk" or "leave" instructions to keep animals away or leave, and squares indicate instructions for the horse to stand up. Refer to Figure 3.9 for the representation of the methods, instructions, and markers.

It can be seen from this figure that the RL-based agent can issue instructions according to the changes in emotional value. For example, for user 1, most of the red circles (come or eat instructions) appear at the local low points of the emotion line (time steps 8, 16, 18, 36, 41, etc.), indicating that the agent often gives approaching instructions when user 1's emotion value drops.

	Rule-based method (blue)	**RL-based method (red)**
Come or Eat	●	●
Walk or Leave	★	★
Stand up	■	■

Fig. 3.9. The representation of the methods, instructions, and markers

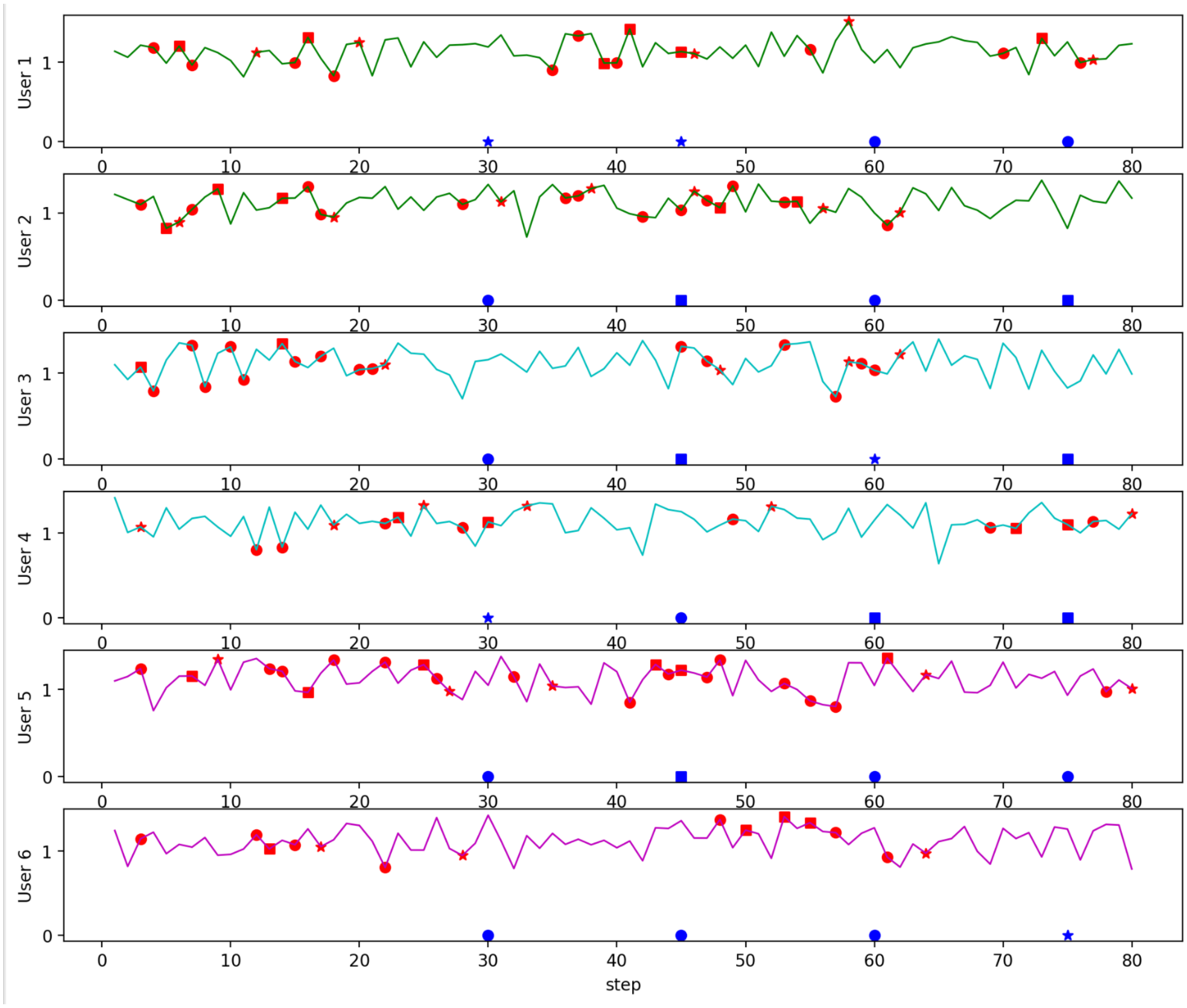


Fig. 3.10. 6 of 100 experimental results. The green line is the EEG curve of simulated users who like animals, cyan corresponds to users who don't like animals, and purple corresponds to natural users. RL-based agent: red markers. Rule-base agent: blue markers. The circles represent "come" or "eat", the squares represent "stand up", and the stars represent "walk" or "leave".

2. Whether the agent can learn rules from simulated user's EEG data?

We hypothesize that the proximity of animals will reduce the frustration value of users who like animals and increase the frustration value of users who don't like animals. The other three emotion values exist and are randomly generated. There are no special changes for natural users.

Through analysis, we get the following **results**:

1. For users who like animals, the RL-based agent gives proximity instructions, which account for about 63% of all instructions for this kind of users and 60-70% of the approach instructions occur when the user's emotion drops. For simulated users who don't like animals, the approach instructions given by the RL-based agent account for 59% of all instructions for this kind of users. The natural user command accounted for 54% of all instructions.

2. The instruction to leave is issued more times to users who don't like animals. But the gap between the three types of people is not large.

3. For the instruction of "stand up", the number of times sent to users who don't like animals is 120%-130% of the number of times sent to users who like animals.

For users who like animals, the agent gives the most "come" instructions. There are fewer instructions to leave. The number of instructions for approaching users who don't like animals have been significantly reduced. **This fits our hypothesis rule.** Compared with the other two types of users, the agent sends "leave" instructions more to users who don't like animals, but this number is not significantly more than the other two types of users.

What puzzles us is the third result. Why does the agent issue so many "stand up" commands to users who don't like animals? We thought it was a problem of bias in the sampled data, but this trend persisted after many experiments. But in the early stage of the design experiment and the reward function, there is no special definition for "stand up" behavior. We observed the session in which there were multiple standing commands, and compared with the rule-based method under the same circumstances.

We found that this result is related to the comprehensive emotional value and distance factor we used. For users who don't like animals, although the approach of animals may cause an increase in frustration value, at the same time other emotions are not affected and will continue to work. Then when the animal is very close to the user, the user's frustration value will rise rapidly under the action of the distance factor. The other three emotional values may rise. When you choose to stand up, the target location of this behavior is a certain distance away from the user. It will not be too close to the user to cause negative emotions, but try to get closer to increase other emotional values. Through learning, the agent finds a strategy to balance the relationship between distance and multiple emotions to maximize the user's positive emotions. This behavior is not in our expected rules. In other words, **the agent has learned one potential rule.** For users who don't like animals, if the frustration value increases when the animal approaches but other values do not decrease significantly, the "stand up" command can be issued to restrict the animal from getting too close and get as close as possible to stimulate user's other emotional increases.

3. Can RL-based agent improve rule-based agent?

It can be seen from Figure 3.10 (blue markers) that the rule-based method sends instruction at a fixed time. Its characteristic is that it will give instructions in strict accordance with our rules.

The disadvantages of the **rule-based method** are:

1. The instructions only give instructions based on a single emotional value, such as User-6 in the Figure 3.10. Within these 80-time steps, at time steps 30, 45, 60, and 75, the instructions are given by the agent corresponding to the user's emotional value at the time. Two are when the comprehensive emotion is declining, and two are when the emotion value has grown. The purple line reflects the user's comprehensive emotion. This shows that instructions given by a single emotion may be biased when facing the user's comprehensive emotion.

2. The instruction given by the agent is fixed time steps, and it is unable to give feedback on the emotional changes between the two instructions.

3. It gives feedback to all users following unified rules. It cannot change the strategy for different users.

The **RL-based method** will give different strategies for different simulated users. From the red markers in the Figure 3.10, the timing of the RL-based agent's instructions is more flexible. It doesn't need to wait for a fixed time, but immediately give feedback based on real-time emotional changes. It is more sensitive to emotional changes and can be changed at any time after the order is issued. The most important thing is that it can be generalized to a more comprehensive data set and learn new potential rules what we didn't know.

Chapter 4

Experiments

Unfortunately, due to the Covid-19 pandemic, experiments could not be performed with VR Zoo Therapy (Zoo Therapy with speech instruction and RL-base Neurofeedback system). However, a follow-up project[**33**] (name «Virtual Reality Zoo Therapy for Alzheimer's Disease Using Real-time **Gesture Recognition**» in the Annexe A) combined the VR Zoo Therapy with gesture recognition and proved the effectiveness by evaluating AD patient's EEG emotion values.

The project uses the VR Zoo Therapy environment and adds gesture recognition interaction methods instead of the speech instruction system of Zoo Therapy. The process of the experiment is also the process of VR Zoo Therapy with speech instruction, only the interaction method is different. The purpose of this project is the same: to reduce the negative emotions of users through immersive VR Zoo Therapy. It is also one of the research goals of our project. At that time, we were very fortunate to have one Alzheimer's disease patient participating in the experience. After using VR Zoo Therapy, the user's frustration values have decreased. We will show the experimental results, the change in frustration value in Section 4.5.

This chapter introduces the purpose of our project, the target population of the experiment, the hardware equipment used, and the experiment process. In the part of the experimental results, we will separately describe the research objectives of the project.

4.1. Target study population

The target study population is the people with subjective cognitive decline (SCD).

To be eligible, applicants had to meet the following criteria:

- Over 60 years old
- Speak French
- Normal or corrected-to-normal vision

- Normal hearing
- Meet the criteria for SCD:
  (1) Self-assessment of worsened memory
  (2) Montreal Cognitive Assessment (MoCA) score between 20 and 30
  (3) No logical memory impairment

4.2. Apparatus

During the experiment, we will use the Fove VR headset to display the Zoo Therapy and the Emotiv EPOC headset to track the user's real-time EEG.

4.2.1. Fove VR

Fove VR (Figure 4.1) is an advanced lightweight virtual reality headset equipped with infrared eye-tracking, orientation tracking, and position tracking systems. It can be used with VR environments developed with Unity 3D using the Fove Unity plugin. It comes with a WQHD OLED display with a frame rate of 70fps and provides 100-degree fields of view providing a high level of immersion in the virtual environment.

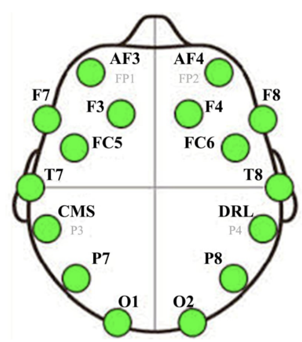
Fig. 4.1. Fove VR headset

4.2.2. Emotiv Epoc

Emotiv EPOC wireless EEG headset (Figure 4.2 (a)) is a commercially available device designed for advanced brain-computer interface applications. In our research, we use the Emotiv Epoc EEG headset detect and recognize emotions in real-time. The headset contains 14 electrodes which are spatially organized according to the International 10-20 system, moist with a saline solution. The electrodes are placed in Antero-frontal (AF3, AF4, F3, F4, F7, F8), fronto-central (FC5, FC6), parietal (P7, P8), temporal (T7, T8), and occipital (O1, O2) regions with two additional reference sensors placed behind the ears. The detailed position of the measured regions is shown in Figure 4.2 (b).

The Emotiv system generates raw EEG data with 128Hz sampling rate as well as the five frequency bands, namely Theta (4 to 8 Hz), Alpha (8 to 12Hz), low Beta (12 to 16 Hz), high Beta (16 to 25 Hz), and Gamma (25 to 45 Hz). The device is furnished with an emotion detection suite that gives emotion values of meditation, frustration, engagement, excitement, and valence normalized in the range 0-1. Maskeliunas and Rytis [**37**] showed in their research that among several consumer-grade EEG devices, Emotiv EPOC performed better. Several studies [**25, 38**] have established the reliability of these outputs.

(a) Emotiv EPOC headset



(b) Emotiv EPOC headset sensors placement

Fig. 4.2. Emotive EPOC headset and sensors placement

4.3. Process of the experiments

We divide the experiment into two sessions.

The first session is the explanation. We explain the format of the study, the details of the experiment process, and how to use interactive instructions to the participants.

The second session is the experiment. The researcher first puts the EEG headset on the participants and then puts on him the VR headset for an immersive experience of Zoo Therapy. They experience AAT in a virtual environment and can freely choose different virtual animals and interact with them. The duration of the immersive experience is about 5-10 minutes. After completing the experience, the Fove VR headset is removed first and then the EEG headset is removed.

In the whole process, the user's emotion value detected by the EEG helmet can reflect in real-time whether the user's negative emotions have decreased.

4.4. Data collection

After the participants put on the Emotiv Epoc at the beginning of the experiments, the emotion values are recorded during the whole experiment. The EEG device transmits brain signals and emotional values at a rate of 128 samples per second. However, to reduce noise, reduce high fluctuations in recorded values, and simplify calculations, the emotion values are smoothed to provide one sample per second. At the same time, the VR environment will also record the emotional value of the participants, the interactive instructions they are in, and the interactive methods that trigger the instructions every second.

4.5. Results

(1) The first objective of this research was to discover that **Is it possible to create an interactive VR environment able to change according to the EEG reactions of the patient?**

In the cooperation project with MS Kibbanahalli Shivalingappa [**33**], we also used EEG to detect the patient's emotional value throughout the experience process and the rule-based method as the Neurofeedback system. The system records the patient's four emotional value changes throughout the process and sends instructions to the virtual animal based on the rules. This shows that Zoo Therapy with the rule-based method can change according to the user's EEG reactions.

(2) The second objective of this research was that **Is it possible to reduce the negative emotions of the patient using Zoo Therapy?**

According to the emotion value recorded in the cooperative project, we analyzed the mean frustration of the participant before, during, and after Zoo Therapy. Results show that, before the therapy, the mean frustration was 0.524, during Zoo Therapy, the mean frustration was 0.429, and after the mean frustration was 0.486. Figure 4.3 shows the difference between the mean frustration before, during, and after Zoo Therapy.

Although this result is carried out under the gesture interaction method, in view of the positive feedback of users under the speech instruction system in Section 3.1.4.2, we believe that the use of voice interaction and the enhanced intervention of the Neurofeedback system can also achieve the same positive effect of reducing user's negative emotions.

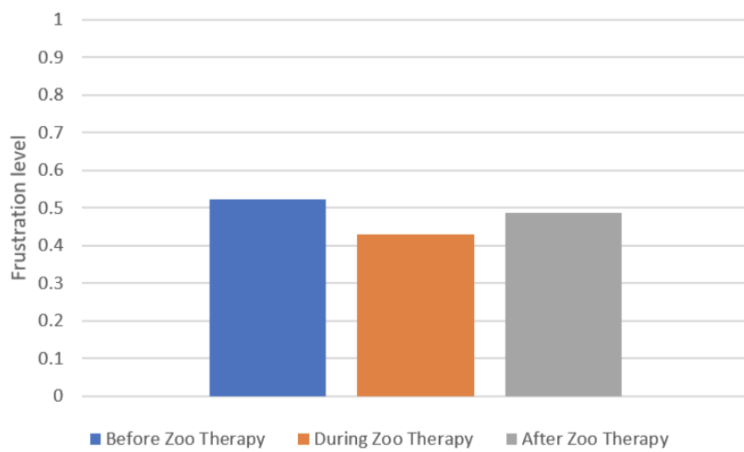


Fig. 4.3. Histogram of general mean frustration

(3) The third objective of this research was to explore **is it possible to acquire new rules of interaction with the patient through the Neurofeedback approach?**

We have experimented this aspect with results which are described in Section 3.2.3.4. Compared with the rule-based method, the RL-based method is more sensitive to changes in user's emotions, and the timing of issuing instructions is more flexible, and the RL- based agent showed the ability to learn the potential rules.

Chapter 5

Conclusion

5.1. Conclusion

In this research ,we aim to design and develop a virtual reality animal treatment that can replace real AAT for Alzheimer's disease, called Zoo Therapy, which stimulates the user's positive emotion feedback through the interaction with the virtual animal dog or virtual animal horse to reduce user's negative emotions and relieve AD symptoms. The salient feature of Zoo Therapy is that in the 360-degree VR HD scenario, users can interact with the virtual animals through multi-interaction methods.

Zoo Therapy uses 3D objects and animal models, and simulates animal actions and sounds through a specially established animal behavior system. The exclusive pathfinding system supports the position change and path update between the virtual animals and the user to assist in completing the interaction between them. The virtual animals can receive different interaction instructions, such as the "Come" instruction, "Eat" instruction, "Leave" instruction, etc., and act according to the instruction. There are three methods to transmit these instructions to the virtual animal: menu panel, speech instruction, and Neurofeedback.

The menu panel is the most common way in the human-computer interaction field. In the VR environment, the participant uses the controller to click the 3D button corresponding to the instruction in the panels to complete the interaction.However, some participants with cognitive dysfunction did not understand how to use the controller. To avoid difficulties for some participants, we have added a speech instruction system.

The speech instruction interaction accepts voice instruction through the trained speech recognition model. The animals can react to the user's voice as if they can hear the user in real life. Five participants participated in the experiment of Zoo Therapy with 3D button interaction and speech interaction. All five users expressed their preference for speech interaction. In the Q&A after the experience, participants were clearly expressed that the virtual horse's reaction made them feel very excited and happy, and they have the illusion of interacting with a real horse.

Different from the above two instructions issued by the user, the Neurofeedback interaction is not a subjective instruction issued by the user. It guides the virtual animal to react to changes in the user's emotions. However, this method has many limitations, such as incomplete rule-making and insufficient flexibility in sending instructions. To solve these problems, we first proposed a method based on reinforcement learning. It can autonomously learn emotional feedback rules for the target population. In the synthetic AD emotional data simulation experiments, the RL-based method is more sensitive to emotional changes than the rule-based method, and the timing of sending instruction is more flexible. More importantly, the experimental results show that the RL-based method can learn the potential emotional rules which the artificial rules are not accurate and hard to extract.

Due to the Covid-19 epidemic, we couldn't conduct experiments on real subjects. However, different interface functions have been tested separately (speech instruction system and Neurofeedback system). Various experimental results are reported in this study. In addition, a follow-up project [**33**] combined the Zoo Therapy with gesture recognition and proved the user's frustration values decrease by evaluating the participant's EEG emotion values.

5.2. Future work

In future work, we plan to add more animals to interact with. We can naturally experience more engagement from the users if they are allowed to choose an animal of their liking in this virtual world. Also, the Neurofeedback systems that rely on reinforcement learning can be trained on EEG data to participate in training. We hope to use intelligent models to further read and understand EEG information and help treat related brain injury diseases, such as AD. Also, the speech recognition system can recognize English at present with very good accuracy. Since most of our target users are francophone, we will train the ASR model to recognize voice commands in French.

We still need to do trials with real subjects with AD. Because of real user variability, EEG feedback may be different from what we expect. We look forward to the end of the epidemic, so that we can improve our project.

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Annexe A

Accepted Paper in International Conference on Genetics, Geriatrics and Neurodegenerative diseases 2020

A.1. Conference

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A.2. Author Contribution

Claude Frasson: Development of idea to a feasible product. Supporting and funding and reviewing the project.

Hamdi Ben Abdessalem: Integration and testing of the developed product. Development of memory and attention exercises.

Marulasidda Swamy KS: Design and train gesture recognition model.

Ai Yan: Develop the Zoo Therapy VR environment.

Virtual Reality Zoo Therapy for Alzheimer's Disease Using Real-time Gesture Recognition

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Abstract. Alzheimer disease affects almost 10 million people every year. Negative emotions such as frustration and anxiety can have impact on brain capability in term of memory functions. Alzheimer's patients experience more negative emotions then healthy older adults. Non-pharmacological treatment such as animal therapy could help Alzheimer patient but has restrictions and requirements. We propose a Virtual Reality Zoo Therapy system in which the patients are immersed in a virtual environment and can interact with animals using their hands. With the immersive experience of Virtual Reality, patients feel that they are in a real therapy room and can freely interact with animals. This system is controlled by an intelligent agent which tracks the patients' emotions using electroencephalography and commands the animals according to their hand gesture and emotions. Experiments have been done and preliminary results show that it is possible to predict patients' hand gesture and interpret them in order to interact with virtual animals and the Zoo Therapy system can reduce the negative emotions.

Keywords: Virtual Reality, EEG, Intelligent Agent, Immersive Environment, Gesture Recognition, Zoo Therapy, Emotions.

1 Introduction

There is an increasing number of people with Alzheimer's disease (AD) and, unfortunately, there is no effective pharmacological treatment that can stop or reverse the disease's progression. It is known that negative emotions such as frustration and stress have an impact on the brain capability in term of memory and cognitive functions and this is visible also in adults with AD.

Non-pharmacological approaches to reduce the impact of symptoms may be interesting. For instance, animal-assisted treatment, can temporarily relieve or improve symptoms. The interaction between an animal and human results in an increase of neurochemical initiating, a decrease in blood pressure and relaxation. This may be beneficial for ameliorating agitate behavior and psychological symptoms of AD [1].

This treatment method has very strict requirements and restrictions on the treatment environment and the animals participating in the treatment. Virtual reality (VR) has proven to be efficient in treating some disorders and could eliminate the restrictions of the real-world methods using its immersion. Thus, a VR system with virtual animals could eliminate the restrictions and requirements of real animal therapy.

However, how the virtual animal can recognize the interaction? Gesture recognition of the patient is a way to detect what command could be communicated to interact with animals present in a VR environment in order to make the environment more immersive and feels like a real work which could attract the patients to actively cooperate with the treatment and increase the treatment effect.

As the system is intended to calm the patient, we need to measure his-her emotions and their evolution. For that we use electroencephalography (EEG) with a portable device that can track the emotions of the patients in real-time. According to the evolution of the emotions we change the behaviour of the virtual animals in order to continue to reduce negative emotions.

In order to create this system, we need to combine VR for immersion, gesture recognition for animal reactions, EEG for measuring patients' emotions and neurofeedback for adapting animal comportment to the patients' emotions. The creation of such a system is complicated because we have to use three different devices at the same time: VR headset, EEG headset and a Hand Tracking device. Each device needs to have a module in order to communicate with it: a virtual environment with the VR headset, a measuring module with the EEG headset, and a gesture recognition module with the Hand Tracking device. The challenge is to synchronize between these modules in order to have a real-like user experience.

Our research questions are: **Q1- is-it possible to predict hand gesture in or-der to interact in a virtual reality environment?** and **Q2 - is-it possible to reduce negative emotions while interacting with animals?**

The rest of this paper is organized as follows. In section 2, we give an overview of the characteristics of AD. In section 3, we present our approach and detail the different modules of the system that we developed. In section 4 we detail the experimental procedure. Finally, in section 5 we present and discuss the obtained results.

2 Related Works

2.1 Animal Therapy for Alzheimer's Disease

Alzheimer's disease is a chronic progressive neurodegenerative disease that usually starts slowly and gradually worsens over time, it is the cause of 60–70% of cases of dementia [2][3]. It has three primary groups of symptoms. The most common symptom is cognitive dysfunction. The second group comprises psychiatric symptoms and behavioral disturbances (for example, depression, hallucinations, delusions, agitation collectively) termed non-cognitive symptoms. The third group comprises difficulties with performing activities of daily living.

The symptoms of Alzheimer's disease progress from mild symptoms of memory loss to very severe dementia [2]. When the situation deteriorates, patients often be-come withdraw from their families or society [2] and gradually lose their physical function, eventually leading to death [4]. The cause of Alzheimer's disease is poorly understood

[2]. No treatments stop or reverse its progression, though some may temporarily improve symptoms [3]. Most of these treatments are palliative.

Current treatments can be divided into pharmaceutical, psychosocial and caregiving. Pet therapy (animal-assisted therapy (AAT)) is a Stimulation-oriented treatment of psychosocial, which is an interaction between humans and animals for therapeutic purposes. It can help someone recover from a health problem or mental disorder. The most used types of AAT are dog assisted therapy and horse assisted therapy. AAT aims to improve patients' social, emotional or cognitive function. A growing body of research shows the social, psychological and physical benefits of animal-assisted therapy in health and education [5]. In aged people, AAT can be used for ameliorating agitate behaviors, psychological, occupational, social and physical disorders especially in Alzheimer and Dementia. AAT can be increase social interactions by initiating decrease the agitate behaviors of patients with Alzheimer and Dementia [6]. People with Alzheimer may have an easier time decoding the simple repetitive, non-verbal actions of a dog. Animals can act as transitional objects, allowing people to first establish a bond with them and then extend this bond to people. Most of the study results revealed that AAT especially dog therapy had an “calming effect” on the patients with dementia and Alzheimer disease [7].

2.2 Virtual Reality and Alzheimer’s Disease

Over the last years, Virtual Reality started to be used in many fields due to its re-markable advantages such as the immersion. There have many reports revealing the benefits of VR for AD patients. Some researchers showed that VR intervention with computerized cognitive training can improve cognitive domains in individuals with mild cognitive impairment or AD [8,9]. Additionally, AD patients prefer completing cognitive training tasks in VR over its pencil-paper counterpart [10]. This technology has been applied in the field of psychology to treat various disorders, including brain damage [11], and alleviation of fear [12].

Most studies focus on the use of VR to help users improve cognitive performances [13,14]. However, several researchers are investigating the importance of VR at a more physiological level [15,16].

2.3 Gesture Detection

Recognizing human action from a video sequence depends on various factors, including the background of video frames, facial expression, and the rate at which position of body changes. An efficient method of information extraction requires removing unwanted background noise and balancing or ignoring varying light effects in different video frames.

There have been efforts to convert 3D coordinate values into RGB image representation for deep neural network training. Encoded RGB image should include extensive temporal and spatial information of skeleton frames in a sequence. Recognizing human gestures using 3D coordinate information is challenging when Alzheimer patients perform gestures. The dataset we prepared for our experiments includes mainly hand-gestures because they are more relevant for any patient to per-form.

The DenseNet [17] helps us derive the best prediction model from challenging the complex dataset. The authors in [18] talks about the effective method for trans-forming the temporal sequence of human skeleton moments into RGB representation. The technique proposed in [18] does not become dependent on the length of the skeleton sequence and efficiently can extract global features. Below are the steps followed in [18] for skeleton sequence to RGB transformation: Encode human poses into RGB images; Enhance local textures of the RGB images by applying AHE [19]; Before feeding images into D-CNN, a smoothing filter is applied to reduce the input noise effect; Discriminative features can be learned by feeding images to DenseNet [17]. DenseNet [17] is one of the most effective CNN architectures for image classification. ESPMF is an enhanced version of SPMF [19], which in turn includes encoded PFs and MFs. The PFs encode skeleton joints position information, and MFs encode the rate of skeleton joints changes concerning all other skeleton joints. The proposed method in [18] achieves the state-of-the-art performance on MSR action data [20] and NTU RGB+D dataset [21]. ESPMF representation shows a 1.42% increased pre-diction accuracy when compared to SPMF [19] representation.

3 Our approach: Zoo Therapy System

In order to reach our goals, we propose a Zoo Therapy System. This system is composed of 4 main components: Zoo VR environment, EEG Measures, Gesture Recognition and an Intelligent Agent.

The users/Ad patients are immersed into Zoo VR environment and an EEG measuring module measures their emotional reactions to the environment. The gesture recognition module tracks hand gesture in real time. The intelligent agent receives the hand gesture and users' emotions in real-time and intervene in Zoo VR by commanding animals depending on the emotions and the gestures of the users. Figure 1 illustrates a general architecture of our zoo therapy system.

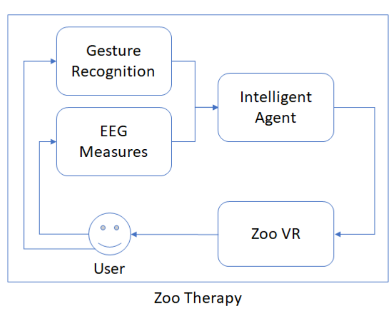

Fig. 1. Architecture of Zoo Therapy

Following is a detailed description for each module of our approach.

3.1 Zoo VR

We propose to create "Zoo VR" which creates a safe and economic environment including animals. In this environment, the user can call the animal to approach, eat or ask it to leave at any time. Animals respond as soon as they receive instructions from users. In addition to the user's gestures, the animals in the environment can also determine the next inter-action by sensing the user's emotions, that is, the changes of the user's emotions will affect the animals' coming and going and some other actions in real time.

Our environment can be divided into five Functional Modules, namely, scene module, animal module, sound effect module, map module and human-computer interaction module. Following a description for each module.

Fig. 2. 3D treatment room

Fig. 3. 3D horse

Scene Module - The overall appearance of the environment. In the scene module, we created a 3D treatment room (shown as figure 2)

Animal models-animals in the environment. The most common forms of AAT are dogs and horses. Therefore, we created a 3D treatment horse and a 3D treatment dog. (Figure 3, the horse is in the treatment room). In order to match the interaction between animals and users, we made some animations while generating 3D animals, such as walking, running, eating, etc.

Sound effect module-environment and animal sound effects. We not only play soothing background music in the entire 3D environment; we also add different animal sound effects. For example, horse and dog can make several different calls in response to different commands from users, and the sounds of horse's walking and eating, the dog's panting. The sound effect will accompany the animal's movement and change in real time according to the different actions of the animal.

Map Module-the trajectory of animal movement and the generation of interactive routes. The function of the map module is to calculate and generate a feasible path according to the animal's real-time position and state, so that the animal will update its state under the path and approach or go away from the user.

Human-computer interaction module-user interaction with the environment. First, the user can interact with the animals by selecting the 3D button in the environment. Then, after completing the model training of the gesture recognition system, we will directly update the 3D button to gesture recognition. Users can use gestures to make animals come, walk, eat or leave. In addition, a neurofeedback system has been added to the environment to influence animal behavior by identifying emotional changes in the user's EEG. When the two instruction modules work together, we give priority to the gesture recognition system.

Finally, we integrate the above five modules. The scene module adds the map module and the animal module, the animal module adds the sound module, and finally connects with the human-computer interaction module. The gesture recognition system and neurofeedback system will then be linked to the map module, the scene module and the animal module to form the final zoo treatment.

3.2 EEG Measures

In this research we use the Emotiv Epoc EEG headset to track emotions. The headset contains 14 electrodes spatially organized according to the International 10-20 system, moist with a saline solution. The electrodes are placed in antero-frontal (AF3, AF4, F3, F4, F7, F8), fronto-central (FC5, FC6), parietal (P7, P8), temporal (T7, T8) and occipital (O1, O2) regions with two additional reference sensors placed behind the ears. The detailed position of the measured regions is shown in figure 4.

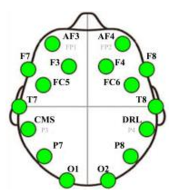

Fig. 4. Emotiv headset sensors placement

The Emotiv system generates raw EEG data (in μV) with a 128Hz sampling rate as well as the five well-known frequency bands, namely Theta (4 to 8 Hz) Alpha (8 to 12Hz), low Beta (12 to 16 Hz), high Beta (16 to 25 Hz) and Gamma (25 to 45 Hz).

The system uses internal algorithms to measure the following mental states: meditation, frustration, engagement, excitement and valence. Although we don't have access to the system's proprietary algorithms, studies have provided evidence showing the reliability of its output [22].

3.3 Gesture recognition system

Our proposed extended SkepexelRel approach for skeleton sequence to RGB representation is motivated by the method explained in [18] wherein the recommended way by [18] produces an efficient RGB image of skeleton sequence. We need a few more modifications on top of the method explained by [18] for real-time prediction applications. Alzheimer's treating use demands a continuous prediction of the patient's hand gestures. Hand gesturing made by the patient changes the virtual environment, and these changes will have a direct impact on the patient's medical status. Data for training is captured from a Leap Motion camera with the Unity platform for basic hand gestures including:

- "Left Hand Come" and "Right Hand Come": will make the animals come near the user,
- "Left Hand Go" and "Right Hand Go": will make the animals goes away from the user,
- "Version2 Left Hand Come" and "Version2 Right Hand Come": will make the animals come near the user,
- "Left Hand Wave" and "Right Hand Wave": will make the animals exit the room,
- "Left Hand Still" and "Right Hand Still": will not affect the animals.

There are two versions of the "Come" gesture since both have different rotation values. Data from the Leap Motion camera provides twenty-six joints information. Each frame data will have the position and rotation values of twenty-six joints. The position represents the joint's actual position in the Unity scene, and rotation values are the rotation of a joint relative to the world coordinate system wherein rotation in all three axes is generated for each joint. With Leap Motion and Unity setup, it is effortless to capture all the details of hand gestures made by Alzheimer's. Rotation values play a very significant role in the hand gesture recognition process. Most of the actions listed above have little variation in position values but will have differences in rotations. Unity updates rotation in all three axes with the help of Euler angles. We need a mechanism to transform both position and rotation values into RGB representation, similar to the method explained by [18]. The figure 5 shows features learned by the DenseNet model with the extended SkepxelRel RGB representation. We experienced a 100% real-time human gesture prediction accuracy in the VR environment.

Fig. 5. Feature maps learned by DenseNet

3.4 Intelligent Agent

In order to personalize the zoo therapy to every participant, The Intelligent Agent tracks the emotions and the gesture of the patient while they are immersed into Zoo VR and intervene in the environment in order to command the animals. The com-mands send to Zoo VR depends on the emotions and the hand gesture of the participants.

The agent uses a rule-based system in order to adapt the environment to the participants. For instance, if the frustration of the participants increases when the animal approaches them, the agent makes the animal go away.

The agent combines hand gesture and emotions as an input in order to make a decision of an action. It starts by given priority to the gestures and tracks at the same time the participants' emotions in order to intervene in case of negative emotions. For instance, if the participant performs a "Come" gesture in order to make the animal come and then the agent detect that his negative emotions are increasing while the animal approaching him, it will command it to go away.

The weight of the rules is updated after each intervention in order to adapt the system to the participant. For example, if the agent makes the animal go away when the participant is frustrated but the frustration doesn't decrease, the agent will understand that the animal is not the reason for the frustration and will decrease the weight of the rule so next time another rule with higher weight will be applied.

4 Experiments

In order to analyze the effectiveness of our approach we started by training the hand gesture prediction module. Hand gestures were performed by ten different subjects, and data from subjects [1, 3, 5, 7, 8, 9, 10] were used for training, and remaining subjects are used for testing. We make sure that testing data has unseen rotations and positions of hand joints to validate the trained model. Leap motion data that we captured for our experiments include actions that can be performed in short duration. Data were obtained at different frame rates supported by the camera and we used the best frame rate for our experiment purpose (30 frames per second).

After that, we aimed to experiment the entire Zoo Therapy system with participants which has these following criteria:

- Older than aged 60 of age
- Francophone
- Normal or correct-to-normal vision
- Normal hearing
- Met the Consortium for the Early Identification of Alzheimer's Disease – Quebec (CIMA-Q) criteria for SCD:
  - Presence of a complaint defined as a positive answer to the following statements: "my memory is not as good as it used to be" "and it worries me"
  - MoCA 20-30
  - No impairment on the logical memory scale based on the education-adjusted CIMA-Q cut-off scores.

Unfortunately, we were not able to perform experiments due to COVID-19 circumstances, but we were able to test our system on one participant. We started by equipping the participant with an EEG headset. When the exercises were complete, we added the Fove VR headset in which we installed the Leap Motion devise (used for gesture prediction) and the participant started the immersive experiment.

5 Results

The first objective of this research was to discover whether **it is possible to predict hand gesture in order to interact in a virtual reality environment**. Results shows that DenseNet architecture can learn unique features for every action from the Leap motion training dataset. Trained DenseNet can predict test images in real-time with 100% accuracy (accuracy graphs are shown in figure 6). We evaluated trained DenseNet in real-time, and it is possible to predict every two-second action in less than 0.5 seconds.

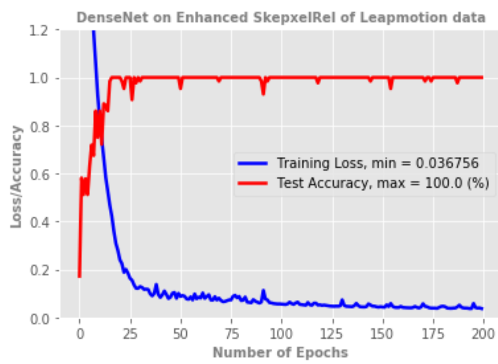

Fig. 6. Learning graphs for Leap motion dataset

The second objective of this research was to analyze **if it is possible to reduce negative emotions while interacting with animals**. To this end, we analyzed the mean frustration of the participant before, during and after Zoo Therapy. Results shows that, before the therapy the mean frustration was 0.524, during Zoo Therapy, the mean frustration was 0.429 and after the mean frustration was 0.486. Figure 7 shows the difference between the mean frustration before, during and after Zoo Therapy.

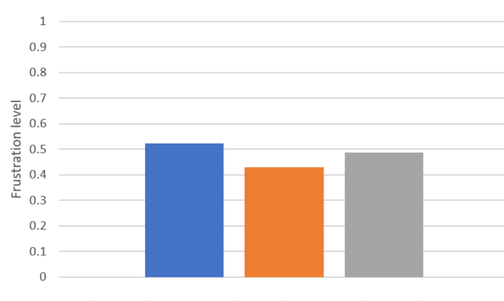

Fig. 7. Histogram of general mean frustration

Even though these results are only from one participant, these results show that Zoo Therapy has the potential to reduce negative emotions and thus reduce AD symptoms.

6 Conclusion

In this paper, we presented a novel approach which could be used to improve AD patients' memory performance by reducing their negative emotions using Zoo Therapy system. We created a VR environment in which we can interact with animals using gesture recognition module. An intelligent agent intervenes in real-time in order to control the animals depending on participants' emotions and gesture. Experiments were conducted during which we collected hand gesture data in order to train the gesture recognition module. We tested our system and results showed that we can predict hand gestures and we might reduce negative emotions with Zoo Therapy system. These results indicate that our system might be used to reduce AD symptoms.

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