Control Architecture Design for Intelligent Robot Assisted Intervention for Children with Autism

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***Abstract*—Robots as therapy tools have been researched into interventional therapy for children with autism to encourage and elicit their novel social behaviors. In order to improve the robots' autonomy and intellectuality in the tasks of user-human interaction, we proposed a novel control architecture, which was based on hierarchical architecture and integrated the core ideas of traditional therapeutic behavior intervention. In this paper, we describe the core thought and components of this control architecture in detail.**

Keywords—Autism; Intelligent Robot; Architecture; DIR/Floortime

I. INTRODUCTION

Autism is a developmental disorder that encompasses a large variety of disorders with impairments in social relationships, communication and imagination. The severity and nature of the symptoms varying from one individual to another [1]. According to surveys, the incidence of autism is on rising, which has reached 1/88 in the United States [2]. Autism has affected the normal development of children seriously and makes a heavy burden for their families.

However, compared with the high incidence and harmfulness, the treatment effect of autism is unsatisfactory. The mechanism of autism is still unclear and the effect of medication treatment is not obvious [3]. Consequently, active research is focused on developing intervention strategies which using behaviors of caregivers and therapists to provoke and encourage social behaviors in children with autism.

With the development of robot technology, researchers attempt to apply robots in the interventional treatment of autism. Recent studies have shown that robot is beneficial in the process of therapy and the children with autism are easier to communicate with the robot than human. While the advantages of robot in the assisted intervention are undeniable, the typical operating mode of the robot is tele-controlled [4]. The defect of this mode is requesting high-quality operators, which prevents the further development and limits the popularization of the robot assisted intervention in autism treatment for the long-term. Therefore, there is a need for therapeutic robots to increase their intellectuality and autonomy, both to lighten the burden on human therapists and to provide a consistent therapeutic experience [5]. The intelligent robot, an active and growing area of robotics research, is the robot's development direction of assisted intervention for children with autism.

The control architecture of intelligent robot, which defines the relationship and the function allocation among the various parts of the whole system, is the logical carrier to realize the intellectuality and autonomy of robot [6]. It is deemed that control architecture design is the primary question about intelligent robot research. Based on the appropriate architecture, the intelligent robot can complete the complex tasks in unstructured environment.

In this paper, a control architecture of intelligent robot-assisted intervention for children with autism was proposed. The content of three aspects has been considered in this process. Firstly, the tasks of assisted intervention for children with autism are summarized, the application situation and future challenges of robot-assisted therapy for autism are analyzed. Secondly, methods of traditional therapeutic behavior intervention for autism are surveyed and selected one of them which named DIR/Floortime. The mechanisms and implementation steps of DIR/Floortime are researched. Thirdly, the control architectures of intelligent robot are investigated and two control architectures of interventional treatment for autism are studied. Finally, we proposed a new architecture which is appropriate to interventional therapy for children with autism using intelligent robot autonomously through integrating the mechanisms of the DIR/Floortime into the control architecture.

II. REVIEW OF RELATED RESEARCHES

Autism is a kind of pervasive developmental disorders and its pathogenesis has not been found. At present, early intervention by educating and training is the mainly method to improve the quality of life for children with autism.

In 1976, Weir S demonstrated that robot plays a positive role in the interventional treatment in a research report [7]. Since then, the related researches have been carried out.

A. The Autism and Robot

Autism is the abbreviation of autism spectrum disorders which refers to a spectrum of psychological conditions characterized by widespread abnormalities in social interactions and communication, as well as severely restricted

978-1-4673-8644-9/16/$31.00

interests and highly repetitive behaviors. Early behavioral intervention is an effective method to reduce the symptoms of children with autism [5]. However, there are some disadvantages in these intervention methods. On the one hand, compared with the current situation of the rising incidence of autism, the workforce of rehabilitation is inadequate obviously. On the other hand, related work on autism rehabilitation by educating and training is boring and highly repetitive, which causes great physical and mental pressure to the therapists. In addition, most children with autism get scared when they face the human and resist to contact with others, leading to low treatment effect.

Since shortages of traditional interventional of autism rehabilitation, the researchers attempted to apply robot as a social tool for autism intervention. The results show that robot is promising for autism intervention and can encourage the children's ability to social communication skills and language. The primary intervention forms of robots include imitation, joint attention, turn talking, dance, music and so on. The most famous related works are studied based on the humanoid robot platforms called KASPAR and NAO robot (as shown in Fig.1).

(a) KASPAR (b) NAO
Fig.1. Children are interacting with robots

Although there is great potential for use in autism intervention, robot should own the ability to complete complex tasks automatically, so that, robot can interact with children without control by operators and be popularized in large-scale especially in home application. To achieve the goals mentioned above, the solution of core challenges is crucial. For example: sensing and interpreting the user's activities and social behavior in the unstructured environment; framing the appropriate robot behaviors in the current social situation. The intelligent robot has potential ability to solve these problems.

B. DIR/Floortime Analyzing

Compared with the robots, the traditional therapeutic behavior intervention for autism has proved its effectiveness in long-term clinical application. In these intervention methods, DIR/Floortime is more popular, which is used by many professional nursing staffs and parents to help children with autism to improve their social interact skills.

DIR is an acronym of the Developmental, Individual-difference and Relationship-based mode, which is invented by child psychiatrists Stanley Greenspan and Serena Wieder [8]. Floortime is DIR model's core method, which basic method and characteristic is to accompany children's activities and interests. In this way, the adults are supposed to create opportunities to communicate with them. Unlike methods such as ABA and TEACHC, DIR/Floortime is more flexible that the fixed process of authoritative and emphasis on the external performance are not advocated, but emphasizes the cultivation of children's emotional experience and imagination, emphasis on interpersonal interaction and personal energy through a lot of intervention strategy.

DIR/Floortime emphasizes the individual of children with autism and does not train speech, motor or cognitive skills separately. Instead, it develops these areas through its focus on emotional development.

The procedures of DIR/Floortime intervention can be summarized as follows:

1) Therapists or parents should acquire the expression of the children with autism such as facial expression, body movement and gesture, intonation, language and so on, by observing and listening. These are the important clues that can help to determine how to close to children.

2) After the children's emotions and behaviors are assessed, therapists or parents can take the appropriate words and gestures to close to them. A round of communication is started based on accepting the children's characteristic of behavior. Then further communication can be extended based on understanding and refinement of the children's interest points at the moment.

3) In the process of the interaction, therapists or parents should follow the lead of children and join into the children's world. It means that the children are the core of the communication and other's intervention actions are proceeding around them.

4) When children accepted other's intervention, the theme of interaction can be extended by the methods include that responding to the children's action which is unconscious or random, asking some questions and making the evaluation of support types.

5) In the process of the interaction, the children make the response for your intervention and use their own way to express their comments. It is time that the children should be guided to close this round communication and start the other one. In this way, rounds of communication are started one by one and the children with autism begin to like and understand the value of this kind of interaction.

C. Robot Control Architecture

Control architecture provides guiding principles for robot system organization and implementation. Establish appropriate control architecture is the key of robot to achieve automation and intellectualization which is the basic ability of an intelligent robot.

With the development of robot technology, different control architectures which adapted to different types robots have been put forward. These architectures promoted the progress of robotics effectively. Control architectures mainly include hierarchical architecture, subsumption architecture, three-layer architecture, distributed architecture and so on [6].

On the basis of these architectures, more various architectures are presented which are used to handle the different tasks of the robot, for example the architecture of competitive networked robot system [9] and The Social Robot Architecture [10].

In the field of robot in interventional therapy for children with autism, David Feil-Seifer proposed a specifically architecture which is one of the behavior-based control architecture named B3IA, a logogram of Behavior-Based Behavior Intervention Architecture [11]. In this architecture, they divided the robot control system into four modules: Sensor and interpretation module, activity history module, behavior network module and effector module. In the behavior network module, there are four submodules: interaction evaluation module, interaction priority module, expressive behavior module and task module, which influence and interact with each other. Except the B3IA, Bekele E T [12] proposed the ARIA (Adaptive Robot-mediated Intervention Architecture) and Wainer J [13] proposed testing-planning-action architecture for robot KASPAR in the task of video game. These architectures played the ideal result in the task respectively. However, in the aspect of improving automation and intellectualization of intervention therapy robot for autism, there are a lot of work to do.

III. CONTROL ARCHITECTURE DESIGN FOR INTELLIGENT ROBOT FOR AUTISM INTERVENTIONAL THERAPY

Through the above description, we can draw a conclusion that using robots or traditional intervention methods in autism intervention therapy, has their unique advantages respectively. Based on the idea that combining the advantages of robots therapy and traditional therapy (DIR/Floortime) in order to obtain more effective treatments, we developed a control architecture of intelligent robot that can be used to realize the specific needs of autism intervention.

A. Complex Task Definition and Reqirments of Intelligent Robot

In the process of autism intervention therapy, robots are used as tools to intervene in the daily life of children with autism. Robots can express their behaviors according to the steps which are summarized from the traditional therapy: DIR/Floortime.

Through the interaction between robots and children with autism, the social interaction skills and emotions of patients could be encouraged. Then the children with autism could integrate into society and grow up healthily.

In order to achieve above goals, intelligent robots must satisfy the following requirements in the intervention context:

1) In the intervention context, robots could discern the user's action and understanding the intention of them. It plays a very important role for the prediction of the user's behavior and the formulation of response strategy of robots.

2) Assess the user's behaviors, then act autonomously for interaction requirements according to certain principles such as the rule of DIR/Floortime.

3) Evaluate the effect of the interaction between robot and user with the specified time, and then adjust the behavior of robot based on the assessment result .

B. The Control Architecture Design of Interlligent Robot for Autism Intervention

The intervention strategies for children are not same because of their different behavioral patterns. In order to achieve the goal to use robot autonomously in interventional treatment, in this paper, we design a control architecture as shown in Fig.2. It combines the tasks of robot and procedures of DIR/Floortime based on the design idea of the social robot architecture.

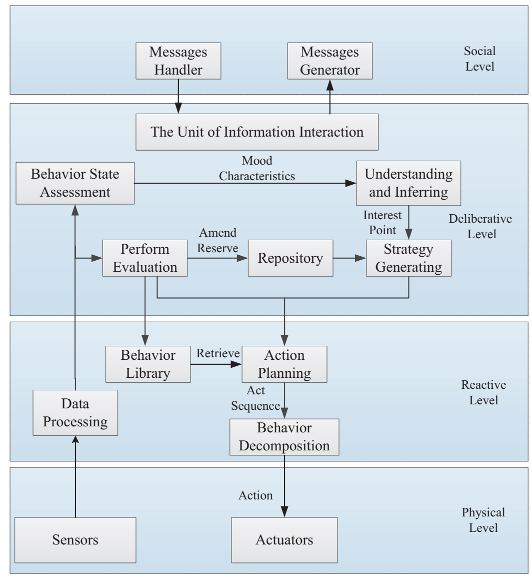

Fig.2. The control architecture of intelligent robot for autism interventional therapy

IV. THE DESCRIPTION OF CONTROL ARCHITECTURE

In the earlier sections, we finished the design of control architecture of intelligent robot for autism intervention. As shown in Fig.2, it mainly includes three levels: social level, deliberative level, reactive level and physical level. In this section, mainly components of each level will be described.

A. The Social Level

The control architecture we developed in this paper is different from the three-layer architecture which is a kind of hybrid architectures, a social level is added. In this way, robot can interact with other agents, such as intelligent furniture, Internet and operators in the working space.

The function of the single robot has several limits. If a variety of interventional therapy methods are integrated into a robot, it will be difficult to realize and the cost will rise widely. So, the robot should integrate communication interface beforehand. Then, the other agents can be used as useful tools assisting robot to finish the task of intervention therapy efficiently for children with autism.

B. *The Deliberative Level*

The deliberative level is the brain of intelligent robot, which is made up of multiple modules, including behavior state assessment module, understanding module, perform evaluation module and strategy generating module.

1) Behavior State Assessment Module

Behavior assessment is a comprehensive evaluation based on observable behavior. It is the precondition to understand children and help them to discover problems. Through behavior assessment, it can provide the basis for the further implementation of intervention programs and evaluate the effectiveness of the intervention. The first step of DIR/Floortime is observation which is behavior assessment. The correct recognition of the children's behavior state is the premise to improve the efficiency of interventional treatment.

Corresponding with this stage, in control architecture, the relevant information is transferred from robot perceptual system to behavior state assessment module. The mood and behavior are assessed by the related algorithms. For the task of intervention therapy for children with autism, following expression should be distinguished.

- Is the children's behavior relaxed and friendly?
- Is the children's behavior scared and opposed?
- Whether children are in their own world?
- Are there some changes in children's behavior state compared with the previous?

2) Understanding and Inferring Module

Knowing how to behave is dependent on understanding the situation at hand. Therefore, the result of behavior state assessment is sent to understanding and inferring module. In this module, the user's mood and intention can be interpreted farther and the interesting point can be obtained detailed.

For example, after a period of interaction, the intelligent robot can identify users' interests and characteristics, such as gestures, actions, sound and so on. In this way, when robot generate strategy of interaction, it can focus on the topic which is enjoyed by the user.

3) Strategy Generating Module

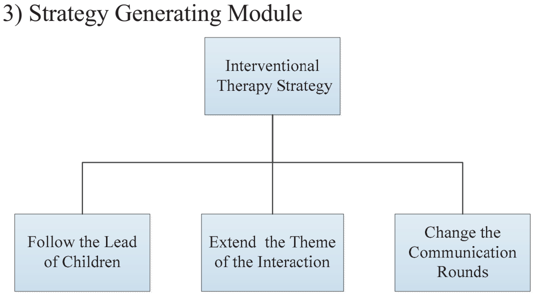

Fig.3. The categories of interventional stage

Children with autism are personalized. Robot should adopt different strategies according to different children with autism or different interventional therapy stages of each child. The strategy generating module of control architecture plays this role.

The core idea of the DIR/Floortime is developmental, individual-difference and relationship-based which accords with the personalized requirement of autism interventional therapy. Combining with DIR/Floortime, the treatment strategy of intelligent robot assisted intervention can be divided into three categories (as shown in Fig.3).

4) Perform Evaluation Module

There is a certain deviation between the robot's actual execution effect and ideal value, especially in the unstructured environment. When robot makes decisions and implements interactive tasks, the user's response must be considered. In order to achieve the ideal interaction effect, the robot should adjust its action according to user's response in real time.

The module of perform evaluation is used to assess the effect of robot's actual execution. In this module, the input is response of the user and after calculation the module output an evaluation index. Then the interventional strategy and behavior of the robot will be adjusted to adapt to the current state of interaction. The user's actions, robot's actions and evaluation will be stored in the database which stored on or off the robot. The data are collected will guide the robot's action in the user-robot interaction later.

C. *The Reactive Level*

The reactive level is the bridge between the deliberative level and the physical level. It is made up of three modules, including data processing module, action planning module and behavior decomposition module.

The data processing module is mainly responsible for dealing with the data collected through various sensors which are installed on the robot frame, including image data, audio data, distance data and so on. The data which have been processed are transferred to behavior state assessment module, then the user's expression can be distinguished.

After interventional strategy is determined, the action planning module retrieves the behavior library, making robot's output behavior. Then, the planned behavior is decomposed by behavior decomposition module and the planned behavior is converted into the robot control program. In the process of action planning, the planning result not only affected by the current state of user-robot interaction but also affected by the previous effect of interaction.

D. *The Physical Level*

The physical level defines the physical components of the robot. It is the carrier of input and output information, which are responsible for the operation of the physical hardware. The physical hardware mainly includes the sensors (such as visual sensors, auditory sensors, distance measuring sensors and so on) and actuators (such as motors, controllers, encoders and so on). To some extent, the physical elements of the robot determine its performance.

E. Execution Steps of Intelligent Robot for Autism Interventional Therapy

1) Through the above analysis, we put forward the general steps of intelligent robot in interventional task, basing on the therapeutic process of DIR/Floortime and robot's control architecture.

2) As shown in Fig.4, the processes of robot in interventional task are as follows:

3) Robot observes the user's behavior through its sensors.

4) Robot assesses the behavior of the user based on the data which obtained through step 1.

5) Based on the result of behavior assessment, the interventional strategy for children with autism is established.

6) Robot's action is planned based on the user's behavior and interventional therapy goal.

7) Robot express action which was planned by its implementing agencies to complete the interactive tasks.

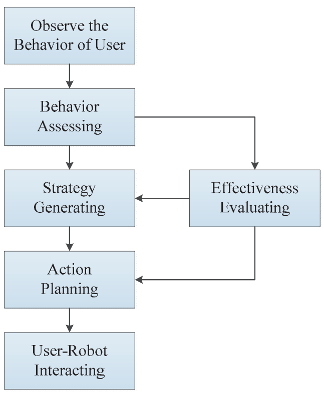

Fig.4. The process of robot in interventional task

In the interactive process, the difference between the actual effect and expected target is evaluated. The assessment result is used to serve for strategy planning and action planning. Then, the robot can adjust its output in real time.

F. The Simulation

In the previous chapters, we have described the design process of the control architecture and analyzed the role of modules. In order to verify the effectiveness of the control architecture, we set up a 3D simulation platform. In this platform, we use the NAO, a kind of humanoid robot, to interact with the child. As shown in fig.5, the preliminary results reveal that the control architecture which we designed is effective.

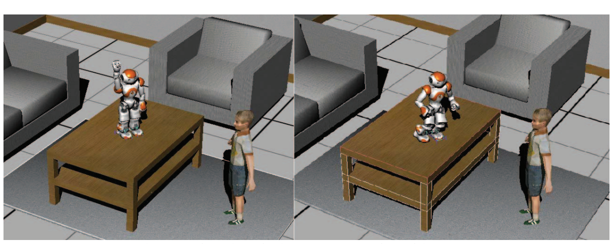

Fig.5. The simulation of control architecture

V. Summary and Future Work

In this paper, a kind of control architecture for robot-assisted intervention for children with autism is proposed to improve the automaton and intellectualization of user-robot interaction. The architecture integrated the idea and strategy of DIR/Floortime. The initial stage of the research proved that application of intelligent robot in assisted intervention for children with autism has great potential. Without control by human and providing respond appropriately are right directions of robot-based autism therapy applications. In order to achieve the above goals, it is necessary to establish a suitable system of the robot structure. In this process, it is an effective attempt to combine the advantages of robot and traditional therapeutic behavior intervention.

The future work involves developing and improving the control algorithm, testing the effectiveness of interaction. We will continue to study the application of intelligent robot assisted intervention for children with autism.

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