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Neuro-Cognitive Virtual Environment for Children with Autism (VECA)

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***Abstract*—Autism a neurological disorder which is often diagnosed during early childhood and can cause significant social, communication, and behavioral challenges over a lifetime. It is increasing day by day and people are inclining from clinical and psychological therapies to assistive technologies. We have developed an interactive virtual environment VECA that aims to enhance the cognitive skills and creativity in children with autism by playing games and interacting with the environment. The setup also incorporates the feedback of the child that whether he/she is comfortable with the environment or not. This solution is cost effective, with no side effects unlike traditional therapies, and can provide valuable insight to the behavior analysis of the autism patients.**

***Index Terms*—artificial intelligence, autism, human tracking, interactive learning, virtual environment**

I. Introduction

A neuro-developmental syndrome known as Autism Spectrum Disorder (ASD) is usually diagnosed in early childhood. It affects the brain development which results in impaired social relationships, monotonous behaviors, limited range of interests and impaired language and communication. Approximately 50-60% of the children with autism are intellectually disabled [1]. Standardized intelligence testing and clinical assessment confirmed that Intellectual Disability arises during the brain developmental period.

An adaptive functioning deficits which result in failure to comply with social, cultural and developmental standards for individual independence and communal responsibility. Without continual support, adaptive deficit limits functionality of the daily life activities, such as social involvement, individualistic living and communication [2].

Studies in Europe, North America and Asia, have indicated autistic individuals with an average prevalence of around 1%. South Korean study identified a prevalence of about 2.6% [3]. The situation is alarming due to the reports from last decade shows an immense increase in the occurrence of autism from approximate 4/10000 to 6/1000 children [4].

There is no universally accepted therapy or treatment for children with autism but there is a growing consensus that comprehensive behavioral and academic programs can boost the social communication ability and remarkably improve long term results for these individuals [4]. Research shows that early intervention treatment services can greatly improve a child's development and the use of computer technology for individuals with autism has constructive and advantageous efficacy. Computer technology as a tool for supporting learning is valuable and motivating for children with autism and parents and clinicians regularly report that children with autism are drawn to technological devices [5], [6].

Traditional therapies have limitations due to huge cost of one-to-one therapeutic sessions and limited number of experienced professionals [7]. Many studies have inspected the use of technology as aided therapeutic tool for children with autism, such as, virtual reality and virtual environment [8], robotics [9], computer technology and multi-touch mobile applications [10].

According to the studies, the environment has a significant influence on the outcome of a child including the development of the brain. For students with learning disabilities who are visual learners, videos, simulations, pictures and other multimedia can be effective teaching tools. We have chosen interactive 3D Virtual environment system for cognitive learning for children with autism because it gives a simplified but explorative learning environment, flexibility of adding new training skills, modifiability, controllability, and it requires only one trained professional.

II. Literature Review

In this section, we provide details of the research work related to this study. Several therapeutic techniques have been used in the past to approach the autism and these are discussed below.

Before the technological treatments for autism was invented, some clinical treatments were practiced. In early 1960's Lysergic Acid Diethylamide (LSD) was used on daily basis as a treatment on 12 autistic children and effect of the drug resulted in their better mood [11]. In 1976 electric shock therapy was introduced, it showed many positive outcomes. A low powered shock was given

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to the patient when he was engaged in activities that were not desirable. According to the results shown this therapy helped in the reduction of undesirable behavior and increase in social behavior [12].

Sinha *et al.* developed an Auditory Integration Training (AIT) [13], and postulated that abnormal sensitivity or insensitivity to certain frequencies of sound waves, regardless of overall hearing ability, was associated with a range of behavior and learning problems, and that his technique of AIT would bring about a re-education of the hearing process. The main idea behind this therapy is that there are peak frequencies in music that make the person hypersensitive. AIT device dampens such peak frequencies and modifies the music. The person listens that electronically modified sound in a two half-hour session for 10 days.

Most of the above mentioned treatments are physical and contains side effects e.g. the shock therapy [12] reported that although the electric shock proved to be the most effective therapeutic agent but it has side many effects like fear of shock apparatus and negative emotional behavior.

Recently, psychological treatments emerged as an alternative means to the physical treatments, and showed better results. Many learning environments have been developed in the past few years to involve the autistic children in certain activities for development of their brain cells so that they can perform well in their daily life. In a study by Gajria *et al.*, it was found that the barrier to teaching social studies to students without and with disabilities is their ability to read and understand written expository text [14]. Hence they used a 'modified graphic organizer' to promote improved expository text comprehension for middle school students with autism.

In two studies desktop Virtual Realities are used to teach the children how to behave in social environments and to understand social conventions. The first study reported that, by using a VR which reproduces a 'virtual café' to teach social skills like how to respond in a café [8]. The speed of execution of the social task of the autistic player in the VR improved after the repetition of the task. The same study showed an improvement of social skills understanding after the VE session. The second study employed a VR which reproduces a 'virtual supermarket' with several exercises about physical, functional and symbolic use of objects, finding that the performance of participants, assessed by specific tests, increased after the VR intervention and one child was able to transfer the acquired skills to the real environment.

In contrast to VR, Collaborative Virtual Environments (CVEs) require two participants for collaboration and interaction and so the load is on both of them to work together. COSPATIAL project [7] located a pair of autistic children in two separate rooms. They were exposed to the same virtual space and so they had to collaborate with each other using headset. This exercise helped in building communication skill, however COSPATIAL is suitable for age group above 5 years.

Another collaborative approach proposed by [10] to enhance the social skills of children with autism is the use of multi-touch tablets as a platform. They have developed simple applications (ages 5-14): drawing, music authoring, photogoo and untangle. Each of which helped the child developing certain skill.

Use of social robots for development of social behavior is another area for ASD treatment. Adaptive Systems Research Group developed a child sized humanoid robot Kaspar with facial and bodily expressions (movements of the head, hand, arms) and expressive gestures to interact with a human. It is programmed to express emotions by smiling, laughing, eyes blinking, frowning, waving arm, hiding face with hands and saying 'ouch' when slapped harder. Interaction of autistic children with Kaspar showed remarkably positive results.

As highlighted in various studies for psychotherapy of autistic children, these approaches are skill specific. None of them is flexible enough to add new features to the system for training different type skills to the children. In this paper we propose a simple yet extensive 3D virtual environment with game based learning approach to enhance critical thinking in children with autism. We have also added a feedback system to examine the comfort level of subject with the environment.

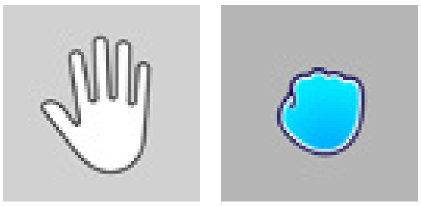
III. Methodology

The proposed system is a combination of game based learning in a virtual environment using artificial intelligence for improving certain skills and a feedback mechanism for analyzing how the child feels in any given virtual environment.

A. *Proposed Design*

Our idea is to design a system that can help in improving cognitive skills and creativity in children with autism. The other objective of our project is to build tools for research in this domain. Our design differs from traditional teaching approaches by presenting an interactive virtual environment. Interaction is done by human gesture recognition, motion detection and tracking with the help of Microsoft Kinect sensors.

We have used hand grip gesture to select any actionable object in the game. When Kinect sensors detect the user's grip gesture state, the cursor switched to a gripped image. The color also changes to assure the user that the grip has been detected. The standard cursor and its feedback graphic is shown in Fig. 1.



(a) (b)

Figure 1. The two modes for controlling the application, (a) the default cursor state, and (b) closed hand for action trigger.

Initially when the subject enters into the virtual environment, a main menu is displayed on the wall.

He/she select any object from the given choices (Red Apple, Blue Ball, and Yellow Lemon). The selection is made by making a grip gesture. According to the selection made a color learning video is displayed. The video teaches the same color the subject has chosen e.g. if apple is selected then the video will teach the color red. Upon selecting an object, the color of the object is stored in the database and floor projection displays the same color. The floor projection gives the subject a very strong visual cue of the chosen color as well as engage him/her by creating ripples wherever he/she moves in the displayed area. The color stays on the floor until the subject choses another color. For creating ripples where the subject moves, we have used depth stream data by detecting skeleton of the user using Kinect Sensors.

When the video ends, two options appears one of them is to go back to main menu and learn another color and the second is to go to activities page. We have built four activities namely:

- Match the color
- Same color objects
- Mimic
- Doodle Board

Activities ‘Match The Color’ and ‘Same Color Objects’ helps in developing cognitive thinking, ‘Doodle Board’ aids in improving creativity and ‘Mimic’ is for keeping the child engaged. Each of them is explained in more detail in application development section. It is to note that the activities ‘Match The Color’ and ‘Same Color Objects’ will use the same color the subject has chosen from main menu.

B. System Setup

The virtual environment is built in a corner of a room equipped with high graphics hardware. Its design flow is shown in Fig 2. We have used front projection because unlike rear projection it doesn’t require additional space. Two projectors are used; one is Acer X1261P on wall and the other NEC m350x is projected on the floor. Its design layout is shown in Fig. 3. Microsoft Kinect Sensor is installed in the room for gesture recognition, motion detection and tracking of human. Its RGB camera is also used to send the user’s images at 3fps for online emotion recognition, it is discussed further in ‘subject feedback’ section.

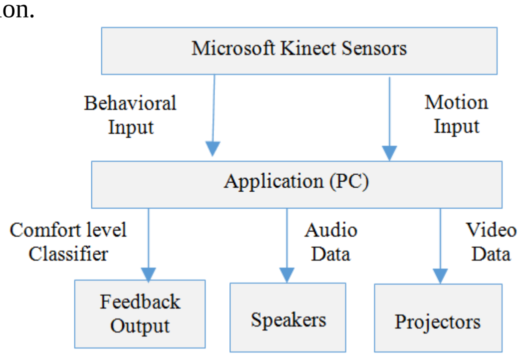


Figure 2. Virtual environment design flow.

The application is built in Microsoft Visual Studio Express using Windows Presentation Foundation (WPF) C# on core i3 series laptop with dedicated video memory of 512MB. For Kinect integration we have used Kinect SDK v1.8.0 and the game graphics are designed in Adobe Photoshop CS6 Extended.

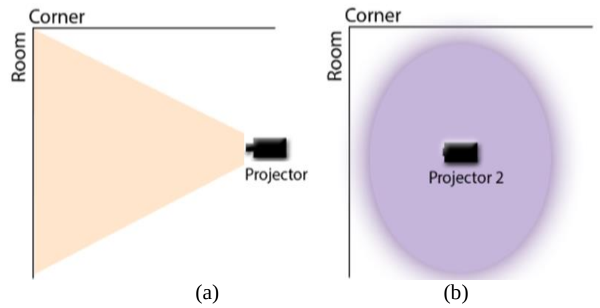


Figure 3. The projector setup, (a) wall projection, (b) floor projection

C. Application Development

Infants of age 2-4 months can differentiate between colors [15] and classify similar shades into categories [16] which shows that color differentiation is the first thing their brain catches. Based on this study we have used color learning as a basis for teaching cognitive skills and creativity.

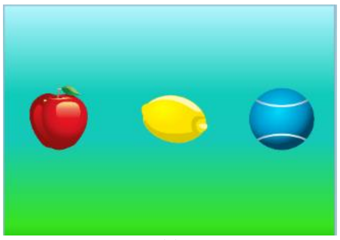
After the splash screen, the application starts with a main screen showing three objects of three different colors (Apple of red color, ball of blue color and lemon of yellow color) shown in Fig. 4(a). The child has freedom of choice on choosing any object he/she likes. The color of the selected object is stored for the later activities in the application. Upon selecting, a video regarding the selected object color is played. The video helps the child in learning the specific color. Simultaneously with the video same color is projected on the floor as well. Wherever the child moves on the floor a ripple is created over there. We have achieved it by following steps:

- Detect user skeleton using Kinect depth sensor.
- Track the user with the help of skeletal joints.
- Use x-axis of joint as x coordinate of the ripple.
- Use z-axis of joint as y coordinate of the ripple.
- Create ripples using WPF shade effects library.

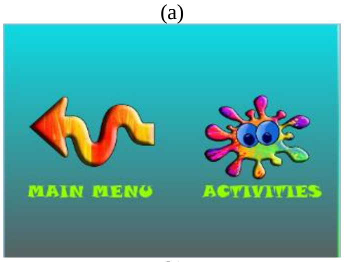
When the video ends the next screen appears which offers two options, as shown in Fig. 4(b). First option is to back to main menu and learn another color go, and the second to go to the next screen for activities. The four activities which developed in this study are shown in Fig. 5(c) and discussed in the next section. The overall flow of the application is described in Algo. 1.

Algorithm 1 Main Menu of Application
Input: String color, string Red, Blue and Yellow
Output: String setection

Initialize Parameters
Initialize Kinect
If object selected then
C = String Value of object
Load video corresponding to color stored in C
Value stored in C is passed as argument to further activities.



(a)



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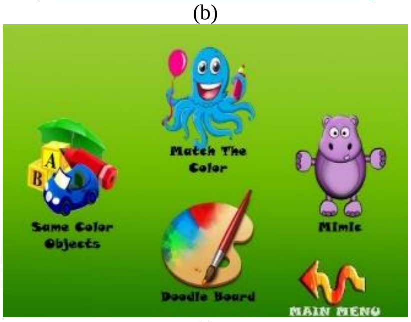
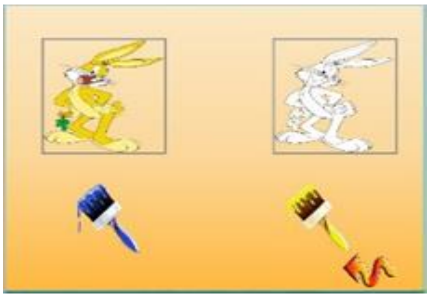
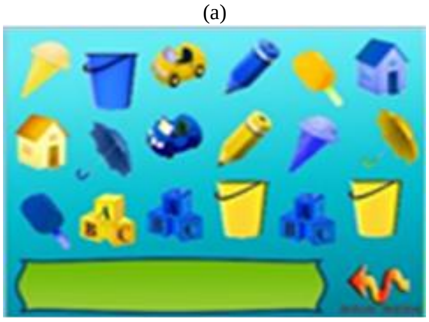


(c)

Figure 4. Shows the (a) color information screen, (b) the main screen, and (c) the activities list.



(a)



(b)

(c)

(d)

Figure 5. Graphical user interface of the activities including (a) fill the color, (b) match same color objects, (c) doodle board, and (d) mimic activity.

D. Interactive Tasks

1) Activity 1: Match the color

The main idea behind this activity is to ask the child to paint a specific color. In this activity there are boxes of two similar images, one is filled with the color that user has selected earlier at the start of the game from the main menu and the second is white. At level one the user is given two choices to fill the empty image. If the user selects the correct color he is be greeted with a dancing avatar and he moves to next level. In the case of wrong color selection, he will be asked to try again. On every new level number of colors in the options increases but for every level the user has to select the same color that he has chosen at start. Algorithm of this activity is described in Algo. 2, and the graphical user interface is shown in Fig. 5(a).

Algorithm 2 Fill the color
Input: String *C* containing color, String *I* for color select, Integer L for level update
Output: Integer for next level
  Initialize Parameters
  If (*I* == *C*)
    Load Video
    L = *L*+1
    Add new color *D* in options
  Else
    Try again

2) Activity 2: Same color objects

In this activity the user has to pick all the objects of same color one by one. For this activity in each preceding level, the number of colors in objects increases to test the learning of the user. For example, in level one, the child will be given two colors to choose from, in level 2 there will be three colors and so on. The algorithm of this activity is given in Algo. 3, and graphical user interface in Fig. 5(b).

Algorithm 3 Match similar objects
Input: String C containing color 1, String D containing color 2, integer L for level update
Output: Integer for next level
  Initialize Parameters
  Load object s with respect t o C and D
  If all objects of C color collected
    Load Video
    L = L+1
    Add new color E objects
  Else
    Try again

3) Activity 3: Doodle board

This activity is a traditional painting application in which there is a pallet of yellow, red, blue and green colors. Upon selecting a color the brush adopts the same color and user has freedom to draw anything using his hand movement. There is a button for clear screen and a button for going back to activities page. The user has freedom to pick any color and draw whatever he likes. The drawing mode is activated when the user makes a hand grip gesture and moves the gripped hand to draw something. The drawing mode is deactivated when the hand is in open state. Fig. 5(c) shows the graphical user interface of this activity, and the algorithm is given in Algo. 4.

Algorithm 4 Doodle board
Input: String B for brush color
Output: Drawing coordinates
  Initialize Parameters
  Load color pallet
  B = selected color
  If hand closed
    Draw with color B
  Else
    Draw = False

4) Activity 4: Mimic

It is a fun activity to draw the attention of the toddlers. A puppet is shown on the screen with flexible arms and legs. The joints of the puppet are mapped onto the joints of the user in front of the Kinect sensor. When the user performs any movement, the puppet mirrors the gesture on the projection screen. This activity is enhances the interaction level of the autistic kid with the virtual environment. The algorithm for this activity is given in Algo. 5, and the GUI is shown in Fig. 5(d).

Algorithm 5 Mimic the movement
Input: Selected Avatar, Current Position, New Position
Output: Avatar movement
  Initialize Parameters
  If new position != current position
    User has moved
    Re-draw draw the avatar to match new position
  Else
    No motion detected

IV. Results

To check if the child is feeling comfortable with the virtual environment we have used the facial features based emotion recognition and the eye contact estimation techniques. During the interaction with the application, spontaneous expressions of the subject are acquired from Kinect and the facial expression eye contact analysis is performed to find the comfort level of the user.

A. Comfortness

Psychologist takes the happiness of the subject as a level of his comfort during the behavioral therapy. Therefore, we have introduced the comfort quantifier in our system which is categorized as either comfortable, neutral or uncomfortable depending on the facial expression.

B. Facial Expression Analysis

Recent advancement in machine learning and computer vision made possible to analyze facial expression in great detail. We have followed the approach presented in [17] for reliable, real-time facial expression recognition for comfort estimation. The main steps we have followed are as follows:

- Viola-Jones algorithm [18] for online face detection.
- Human Visual System (HVS) based salient region defined in [17] are cropped.
- Mouth region is selected as salient feature for happiness, neutral or sadness.
- Pyramid of Local Binary Pattern based feature extraction approach.
- Extended Cohn-Kanade Dataset database to train the classifier for Expressions.
- SVM based direct classification technique for facial expressions

C. Eye Contact Estimation

If the child is focusing on the display, it ensures that the child is taking interest, and the comfortness parameter shows how positive or negative the child's response is towards the interactive virtual environment. If the child is uncomfortable then his attention can be drawn to floor by prompting a new interactive floor projection.

Using these parameters VECA can be made self-adapting.

The director of Step to Learn (STL), an autism resource center, reviewed the setup and proposed further applications for the autism patient of the center for enhancing the academics skills like learning numbers, alphabets, words and shapes as well. He also added that making such fun learning activities for adolescent with autism is very beneficial for their growth.

This study is highly scalable and new learning activities can be added for each age group. The grip gesture gets recognized with 95% accuracy, even with cluttered background. The facial expression achieved the hit rate of 83%, while the eye contact estimation was 87%. For the floor projection, the activity produced at the user location had a deviation of +/- 12cm. The response for selecting an actionable object by the grip gesture had no errors and was spontaneous.

V. Conclusions

Shyness in individual behavior or disinterest in the social interaction is very prominent in ASD individuals and we were successful in lowering it in the virtual environment. The proposed setup showed promising results for improved learning pattern of the individual, and greater eye contact with the environment. The applications can be tailored according to the need of the individuals or the requirements of the professional psychologists.

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