Robot mediated therapies for improvement in social interaction of ASD children

Author

FAISAL MEHMOOD

Registration Number

00000171963

Supervisor

DR. YASAR AYAZ

DEPARTMENT OF ROBOTICS AND INTELLIGENT MACHINES ENGINEERING

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

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DR. YASAR AYAZ

Thesis Supervisor's Signature: ____

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MASTER THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by: **Mr. Faisal Mehmood Regn # 00000171963** Titled: **"Robot mediated therapies for improvement in social interaction of ASD children"** be accepted in partial fulfillment of the requirements for the award of **MS Robotics & Intelligent Machine Engineering** degree. **(Grade_____)**

Examination Committee Members

1. Name: Miss Sara Baber Sial — Signature: _______________

2. Name: Dr. Muhammad Jawad Khan — Signature: _______________

3. Name: Dr. Muhammad Naveed — Signature: _______________

Supervisor's name: Dr. Yasar Ayaz (HoD R & AI) — Signature: _______________

Date: ___________________

_________________ Head of Department

____________ Date

COUNTERSIGNED

Date:__________

______________ Principal

Thesis Acceptance Certificate

It is certified that the final copy of MS Thesis written by ***Faisal Mehmood*** (Registration No. ***00000171963***), of Department of Robotics and Intelligent Machine Engineering (SMME) has been vetted by undersigned, found complete in all respects as per NUST statutes / regulations, is free from plagiarism, errors and mistakes and is accepted as a partial fulfilment for award of MS Degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in this dissertation.

Signature: ___________________

Name of Supervisor: Dr. Yasar Ayaz (HoD R & AI)

Date: ___________________

Signature (HOD): ___________________

Date: ___________________

Signature (Principal): ___________________

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Declaration

I certify that this research work titled "*Multi humanoid robots-based interventions for social interaction improvement of Autistic child"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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FAISAL MEHMOOD

2016-NUST-MS-RIME-00000171963

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Faisal Mehmood

Registration Number :00000171963

Signature of Supervisor

Supervisor: Dr. Yasar Ayaz (HoD R & AI)

Copyright Statement

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Abstract

Children are typically divided into three major categories. They are: autistic, down syndrome and typically developed children. In this research, we will be dealing with autistic children. Autistic children are biologically fit, and they usually do not have chromosomal disorder in them as down syndrome have, so their mental and physical development is approximately synchronized and better as compare to down syndrome children. Since this is not true in all autistic children, so few of them face issues in their interaction with people living around them. It is observed that children are more deviated towards toys and especially robots. Three major categories of robots are: aerial, mobile and humanoid robots. Research also shows that appearance of robots also affects autistic children. Closer the appearance of robot to a human being, larger will be the impact on these subjects, which shows their tendency towards humanoid robots. Researchers are introducing humanoid robots in education, improving social interaction, elimination of different disorders of life and many other related things. This thing falls in the category of Human Robot Interaction (HRI) in autism research filed. Different deficits which are common in these children are: lack of joint attention, lack of verbal and nonverbal communication, imitation, and motor movements.

In this work we are designing two different robotic therapies, using two NAO robots. First therapy is for measuring joint attention and then it’s improvement and other one is for improving imitation skills based on joint attention, measured and improved in previous therapy. In first intervention, we are designing a multi humanoid robot based joint attention measurement system first and then integrating it with different types of reinforcement stimuli for transforming it into joint attention improvement system. These reinforcement stimuli are arranged from least effective to most effective and their effectiveness varies depending upon the behavior and sensitivity of each child. In second intervention, we are designing a multi humanoid robot based imitation system actuated by joint attention of ASD child. In both interventions, we are accessing the cognitive state of brain of ASD child as well. Accessing cognitive state of brain, before and after each therapy, is added just to note the impact of therapy on ASD child. We are noticing the mental presence of child via accessing his / her cognitive state of brain. We are also utilizing skeletonization for tracking motions of different body parts of child during both interventions.

Key Words: *Autism, Robotic Intervention, NAO robot, Emotive EEG headset, Human robot interaction, Cognitive state of brain, ASD children, Joint attention, Imitation, Reinforcement stimuli, multi robot interventions.*

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASD	Autism spectrum disorder
DS	Down syndrome
TD	Typically developed
AOSI	Autism Observation Scale for Infants
HRI	Human Robot Interaction
ABA	Adaptive Behavior Analysis
SAM	Socially Animated Machine
EEG	Electroencephalography
TCP	Transmission Control Protocol
S	TCP Server
C	TCP client
CD	Client Descriptor
OS	Operating System
LTM	Least to Most
PQ	Priority Queue
FSM	Finite State Machine
TO	Time Out
TH	Target Hit
JA	Joint Attention

CHAPTER 1

INTRODUCTION

The research work in this dissertation has been presented in two parts. First part is related to designing of multi humanoid robot based joint attention measurement and improvement system with different reinforcement stimuli. The objective of this part is to briefly describe the joint attention issues in ASD children and a novel approach to quantitively measure and improve it using humanoid robots, NAO. Inclusion of different reinforcement stimuli helps us to get some information about the sensitivity of ASD child towards a scene. The second part is related to designing of multi humanoid robot based imitation system actuated by joint attention of ASD child. This system is adaptive to joint attention of ASD child which is linked with previous intervention. The objective of this part is to completely describe about another major deficit in ASD child, i.e., imitation problem and another novel approach to measure and improve it in these subjects. In both interventions, there is a section which deals with accessing of cognitive state of brain of ASD child before and after these interventions.

1.1 Background, Scope and Motivation

Autism spectrum disorder is a neurodevelopment disorder which affects different aspects of a person who is being suffered from it. Proper treatment and early detection are necessary to overcome these difficulties. Children are of different kinds and they have been divided in three different categories. They are: autistic (ASD), down syndrome (DS), and typically developed (TD). Autistic and down syndrome children are rated and evaluated using another targeted group, which acts like a reference, called typically developed children. Similarly, there are different other categories on scale of autism. They are: Asperger syndrome, High functioning autism, mild case, and Low functioning autism. There are different ways which are being used to give treatment to these ASD children ranging from robotic interventions to medication. There are three basic kinds of robots which are present to date. They are: humanoid, mobile and aerial robots. Research shows that robotic interventions in case of autism, are producing positive effects in the life of ASD children. The common deficits in ASD children are: lack of joint attention, lack of imitation skills, verbal and nonverbal communication issues, different motor movements, and different sensory issues.

Physical appearance of robot matters for ASD children. Closer the appearance of robot to human's appearance, more skills will be transferred to ASD children [1, 2]. It has been observed that humanoid robots have large impact on ASD children in robotic intervention because of their huge resemblance with human being. Mobile robots' impact is coming after humanoid robots' impact. This research filed is emerging with the revolution in robotics.

The scope of above mentioned research field is too much broad. There are different prominent and important areas of applications of chosen research filed. They are:

I. Humanoid robots in education

   Robots, having high impact on children, are being introduced in education sector. They are used to teach basic things to children. It has been observed that robots teach few things very well to children as compare to human instructor.

II. Humanoid Robots in industry

   Industries are being automatized due to revolution in robotics stream. Many robots are working side by side with human being and playing a vital role in our production sectors. How should robots interact with each other and with people working around them is what that falls in human robot interaction research field.

III. Humanoid Robots in home

   Due to advancement in technology and decrease of price of social robots, people are continuously buying robots for their domestic use. Robots are utilized to clean rooms, reminding important events, and even as a peon of home. Here again, how robots will have to accomplish all his duties without interfering and harming humans around him, falls in the category of Human Robot Interaction (HRI) research field.

IV. Humanoid Robots as companion

   Usually humans are companion of humans but in current era its being changed. Now robots can also be a companion of human being. Robots can give limited suggestions to people residing around him and even can connect people with other people. Introduction of artificial intelligence in robots made robots able to think and take right decisions based on learning period provided to them.

V. Humanoid Robots as care taker in hospital and elderly homes

In hospitals and elderly homes, robots are being used as servants that can repeat same action multiple times which a human being cannot because sometimes human will become frustrated. Here again people are involved, and robots must directly interact with people, so again we must give guarantee of a safe, harm less and effective interaction and all these things fall in Human Robot Interaction (HRI) research field.

Our youngsters are our strength and nations are highly dependent upon skilled and professional young generation. These youngsters have also passed through their childhood. If, somehow there remains a gap in mental and physical development of young generation in their respective childhood, then this thing raises an alarming signal to the progress and position of a country in the world. It is said that each person is autistic up to some extent, especially children are more up to higher extent. These things lead towards severe deprivation of things and even destroy nations' legacy in terms of glory, progress, international relations and status. If these things are over come at earlier stages, in childhood, then it's possible that we will be having wonderful minds among those who are currently being affected by autism and it might possible that we will be having leaders with in our nation in different streams of life who will give something more productive and durable not only to our nation but to the human being of the whole world.

1.2 Autism Spectrum Disorder

Autism spectrum disorder is a neuro development disorder which affects different social skills of autistic person. There are multiple social skills which are too much important in daily life communication, e.g., joint attention, imitation, verbal, nonverbal, motor movements, many sensory issues, gait and facial expressions etc. Autism directly affects either one of them or all of them. In order to quantitively measure the autism, [3] has developed a scale called Autism Observation Scale of Infants, abbreviated as AOSI. According to this scale, we can classify different infants with respect to autism case. There are different mechanisms which are being used for the early detection of autism in children. Most common approach is to contact corresponding therapists and psychologist, dealing in autism. These people identify the autism and rate it according to AOSI [3]. Normally, they divide autistic children into three major categories: Asperger syndrome, Low functioning autistic, and Hi functioning autistic etc. Curing of autism is possible via two major ways: medication, and interventions. We are dealing in treatment of autism via interventions. Now interventions are also broadly classified into three categories: human based interventions, robot-based interventions and human-robot based interventions. There are different symptoms for detection of autism in children e.g., you will find some motor movements, which will be repetitive unnecessarily, lack of joint attention while interaction with people and things surrounding them, lack of imitation skills, lack of verbal and nonverbal communication, and delay in paying attention to different sensory stimuli. Despite this, there are different bio-markers as well, which are used for the detection of autism.

1.3 Interventions for Autism Spectrum Disorder

Three types of interventions for Autism has already been mentioned, above paragraph. Human-Human interaction-based intervention is most conventional one which is also being used right now where robotic based interventions have not been introduced yet. Human-Robot and only Robot-based interventions are recently introduced in this filed. In both types, this thing falls in Human-Robot Interaction (HRI) research field. Research have proved that robotic interventions are also capable of medicating autism in children [4], [5], and [6]. Depending upon the deficit, which ASD have, different interventions are used e.g., joint attention lack [7], imitation lack [8]. Commonly used interventions are: ABA, Speech therapy, PT, circle time, and many others. There are multiple factors which affects the interventions for ASD children being conducted by robots, such as physical appearance, interactivity, motion sequence and learning motivations [9].

1.4 Robotic interventions for Autism Spectrum Disorder

In human robot interaction, different children will be having different initial responses [10]. Robotic interventions are now being introduced in Autism Spectrum Disorder domain. These interventions are designed based on specific strategic plans which are suggested by either therapist or psychiatrist. The robots which are being used in these therapies are different in nature [11]. Few are humanoid, like human being in appearance, [12], few are anthromorphic and few are zoomorphic. [4, 8, 13, 14] and [7] presented few robotic based interventions and knowledge of robots being used in autism spectrum disorder. These robotic interventions are targeting either one deficit or multiple deficits present in ASD children, as mentioned above.

1.5 Types of robots and their appearance

Robots are categories in to three major types. They are: aerial robots, mobile robots, and humanoid robots. Each type of robot has its own physical and functional limitations. According to different applications and uses, their roles are also different from each other. In autism, we usually use either mobile or humanoid robots or sometimes a mixture of these as well. Children with ASD are more deviated towards these robots to whom they consider toys mostly. [15] has presented a comparison between TD and ASD children regarding their perception about these robots. They reported that most of the TD and ASD children, categories these different types of robots as toys. While they have also reported that few ASD children also categorized them as machines. [11] presented different robots which are being utilized in autism spectrum disorder, few of them are shown in figure 1.1, and figure 1.2, below.

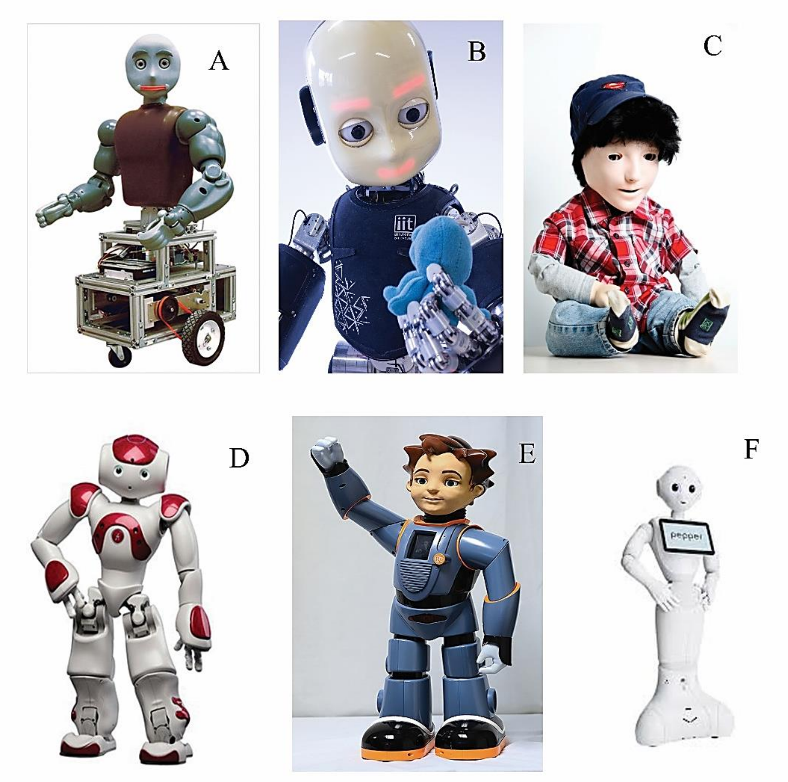

Figure 1.1: Different types of humanoid robots available in Autism Spectrum Disorder

Figure 1. 2: Different types of non-humanoid, partially humanoid, and humanoid robots available in Autism Spectrum Disorder

These different robots belong to different categories with in humanoid and mobile robots. They are further divided into two more categories: Anthromorphic and zoomorphic robots.

Table 1-1 Robots along with their names, given in figure 1.1

Figure Number	Alphabet Allotted	Robot's Name
1.1	A	Bandit
1.1	B	iCUB
1.1	C	KASPAR
1.1	D	NAO
1.1	E	ZENO
1.1	F	Pepper

Anthromorphic robots are the combination of animal and humanoid robots while zoomorphic robots are completely animal like structure. All these robots along with their name and allotted letters are given in table 1-1 and 1-2.

Table 1-2 Robots along with their names, given in figure 1.2

Figure Number	**Alphabet Allotted**	**Robot's Name**
1.2	G	Keepon
1.2	H	Charlie
1.2	I	Pleo
1.2	J	Roball
1.2	K	Muu
1.2	L	Robota Doll
1.2	M	Tito

Near autistic children, appearance of robots matters highly [16]. It is observed that those robots have higher impact and capable of transferring high social skills, which closely resemble with human being, [1] and [16]. Moreover, different types of sensing technologies [17] , being used in autism, have proved that initial responses of ASD children towards humanoid robots are more as compare to other robots [10]. Interacting with robots physically, is one of the most initial response of ASD child. [13] used tactile sensing technology for capturing this information. There are different roles of robots in autism spectrum disorder. They are: therapeutic playmate , social mediator, and model social agent [2] along with different controlling schemes [18] so that human robot interaction can make more and more collaborative and independent so that it resembles to natural reactions of human beings. [19] checks that whether joint attention is dependent upon different social cues being given by robot? Along with these social cues, emotions recognition is also important because it will be a key of successful human-robot interaction. For this, [20] introduced Socially Animated Machine (SAM) which preserves the characteristics of human being while the body appearance is like animal. Moreover, NAO robot can also opt different emotional postures which can be perceived differently by different people [21].

1.6 EEG of brain of ASD children

EEG stands for electroencephalography. In robotic therapies, we can access the cognitive state of brain of ASD child as well [22]. These EEG analytics when integrated with eye tracking [23] can be used to give more accurate results in describing the neural correlation between joint attention shift and initiation of joint attention. Similarly, [24] reported that the inter-hemisphere coherence of ASD children reduces in a chair and face matching game while in cased of TD children, it was not so. For the assessment of attentiveness of child, we studied alpha band only which describes different situations and states of mind [25]. Different resting-state electroencephalography schemes have also been discussed in [26].

1.7 Aims

- Designing a multi humanoid robot-based joint attention measurement system for ASD children.
- Designing a multi humanoid robot-based joint attention improvement system for ASD children with reinforcement stimuli.
- Designing a multi humanoid robot based imitation system actuated by joint attention of ASD children.

1.8 Hypothesis

I. Multi-humanoid robots, with reinforcement stimuli, can measure and increase the joint attention of ASD children.

II. Improved joint attention, based on above hypothesis, can be used to increase the accuracy of imitation skills.

CHAPTER 2

ARCHITECTURE OF DESIGNED ROBOTIC THEREAPUTIC INTERVENTIONS

This chapter thoroughly defines the complete architecture of designed interventions. It is divided into two parts. Part one deals with intervention one and part two deals with intervention two.

2.1 Multi Humanoid Robots Based Joint Attention Measurement and Improvement System with and without Reinforcement Stimuli (PART A)

This multi humanoid robots-based system is designed for measuring the joint attention of ASD child quantitatively which cannot be easily measured manually. After measuring and rating the joint attention of ASD child, we introduced joint attention improvement system which is also utilizing some reinforcement stimuli as well. Integration of reinforcement stimuli in joint attention measurement system, leads us towards the measurement of sensitivity of ASD child towards different stimuli being occurred in a real-world scene to whom he / she is looking.

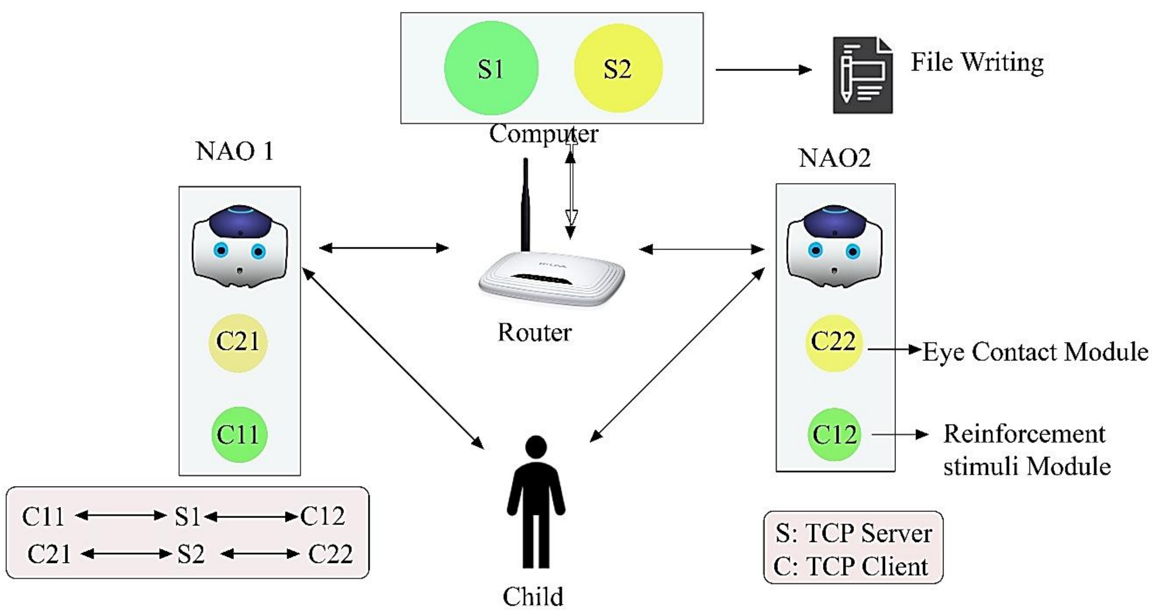

Figure 2.1: Architecture of joint attention measurement and improvement system

2.1.1 Joint attention of ASD child:

Joint attention is most important social skill which enables a person to quickly and properly respond towards the changes being occurred around him / her. Shifting of attention towards demanding stimulus with lesser delay, is important for meaningful communication. This skill is weaker in ASD children due to which they are unable to properly shift the attention towards attention demanding stimulus. In other words, you will find many of ASD children unaware of their surrounding situations if they are not really paying attention. [7] investigated that: is it possible to use different humanoid or mobile robots in different therapeutic interventions to capture the attention of ASD children? [19] investigated the necessity of different social cues given by robot during therapeutic intervention because these cues will be used to capture the attention. Later, they compared the impact of robotic intervention, and same intervention, conducted by some human being. [27] investigated that how ASD children explore the 4-D space (3D spatial and 1D time) during robotic task based on assessment of joint attention. This intervention was also tested with human being as well and it is reported that, ASD and TD children were performing well with human therapist as compare to robotic mediator and ASD

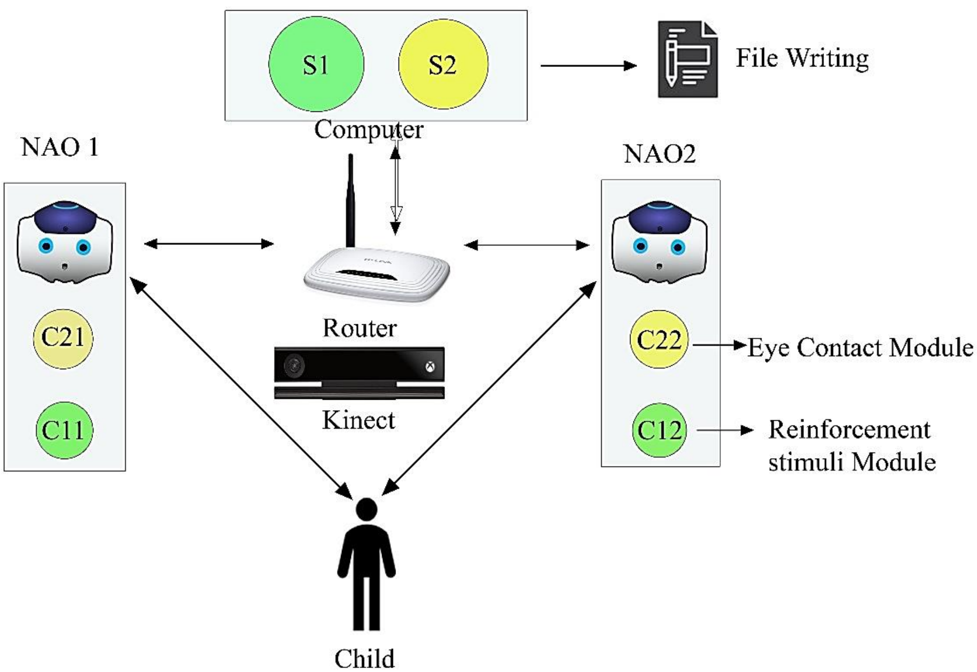

Figure 2.2: Extended architecture of joint attention measurement and improvement system

children were having less score as compare to TD children. Multiple sensing technologies are used to capture joint attention of ASD child [17].

2.1.2 Architecture Explanation

Consider figure 2.1, there are three major modules, NAO Robot 1, NAO Robot 2, Computer along with ASD child and a network router. In computer block, we have two TCP servers, denoted by $S_1$and S_2. In each NAO Robot, we have two different modules, eye contact measuring module and reinforcement stimuli module. Both modules are thread safe and running in parallel fashion. These modules are integrated with TCP clients, which are represented by C_{ij}. Note down the color-coding scheme in figure, which illustrates the connection and communication between these TCP clients and TCP servers. These communication details are as under:

$\boldsymbol{S_i}$**:** Where i is server number.

$\boldsymbol{C_{ij}}$**:** Where i is server number, to whom this client must be connected, and j is client number connected to server i.

So,

$\boldsymbol{S_1}$**:** TCP Server one, controlling reinforcement stimuli modules running on both NAO robots.

$\boldsymbol{S_2}$**:** TCP Server two, controlling eye contact detection modules running on both NAO robots.

$\boldsymbol{C_{11}}$**:** First TCP client of Server one (integrated with reinforcement stimuli module), running on NAO one.

$\boldsymbol{C_{12}}$**:** Second TCP client of Server one (integrated with reinforcement stimuli module), running on NAO two.

$\boldsymbol{C_{21}}$**:** First TCP client of Server two (integrated with eye contact module), running on NAO one.

$\boldsymbol{C_{22}}$**:** Second TCP client of Server two (integrated with eye contact module), running on NAO two.

Both servers are independently running on computer and controlling their corresponding modules. They are writing information to a text files for off line processing. All these clients and servers are communicating and sharing information with each other through a wireless network which is full duplex communication. Figure 2.2 is the same thing only we introduced Kinect V2 sensor in whole setup for noticing the diversion of attention of ASD child.

2.1.3 Networking information

Figure 2.3 gives all of networking information of whole system of intervention. We used static IPs for NAO robots along with TCP servers. Network IPs of TCP servers and NAO robots are different. TCP servers' IPs are same of computer's static IP address. This network address belongs to class A of networking address range. Despite of having same IP addresses for different servers, information and data were remaining separate from each other because ports for communication of both servers were different. You can set network address range and IPs according to your own ease but keep this thing in your mind that you must have to declare / assign static IP addresses to these devices for proper working of this network.

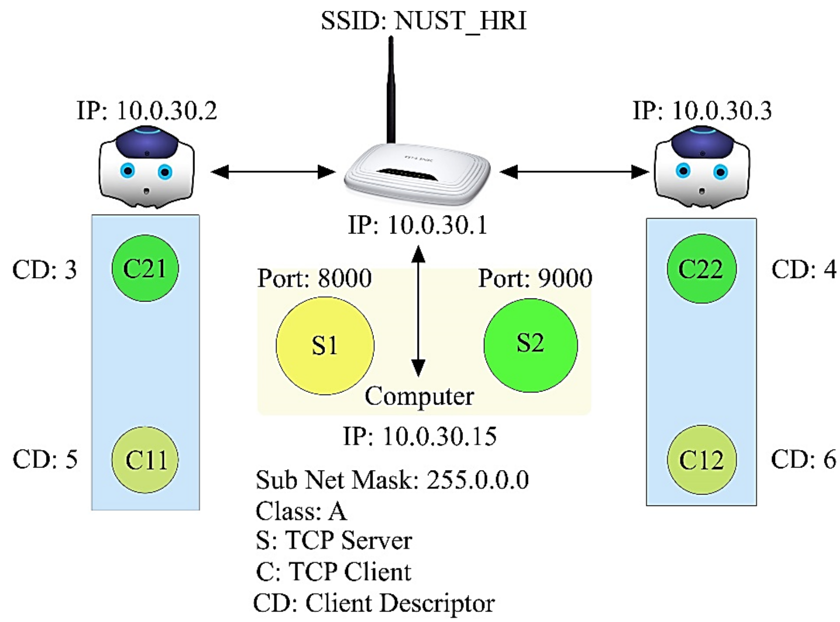

Figure 2.3: Networking details of joint attention measurement and improvement system

CDs are client descriptors which are allotted on run time process. NAO's OS default communication port is 9559. You must ensure that none of your server is using this channel for communication because it will not work. This channel is reserved for communication with NAO robot. Moreover, try to use higher port for communication, start from 5000 or 6000. Higher port numbers are usually vacant in a network and hence reduces the chances of communication interference.

2.1.4 Intervention sequence and setup hierarchy

Consider figure 2.4 which represents the intervention sequence and complete setup of therapy. Intervention room is divided into three different parts via two partitions. Extreme left part is reserved for accessing cognitive state of brain of ASD child (Recording EEG) before and after the completion of each therapeutic intervention. While extreme right part is reserved for user, controlling NAO robots and other sensory devices. The middle part is reserved for therapeutic intervention of ASD child. There are total three stages through which an ASD child will pass. Initially he / she will report in extreme left part, for the assessment of cognitive state of brain. Latterly, he / she will be sent in to intervention area where the intervention takes place and after the completion of therapeutic intervention, he / she will be sent to left part (EEG recording area) for the assessment of cognitive state of brain so pre and post intervention steps are, assessment of cognitive state of brain of ASD child.

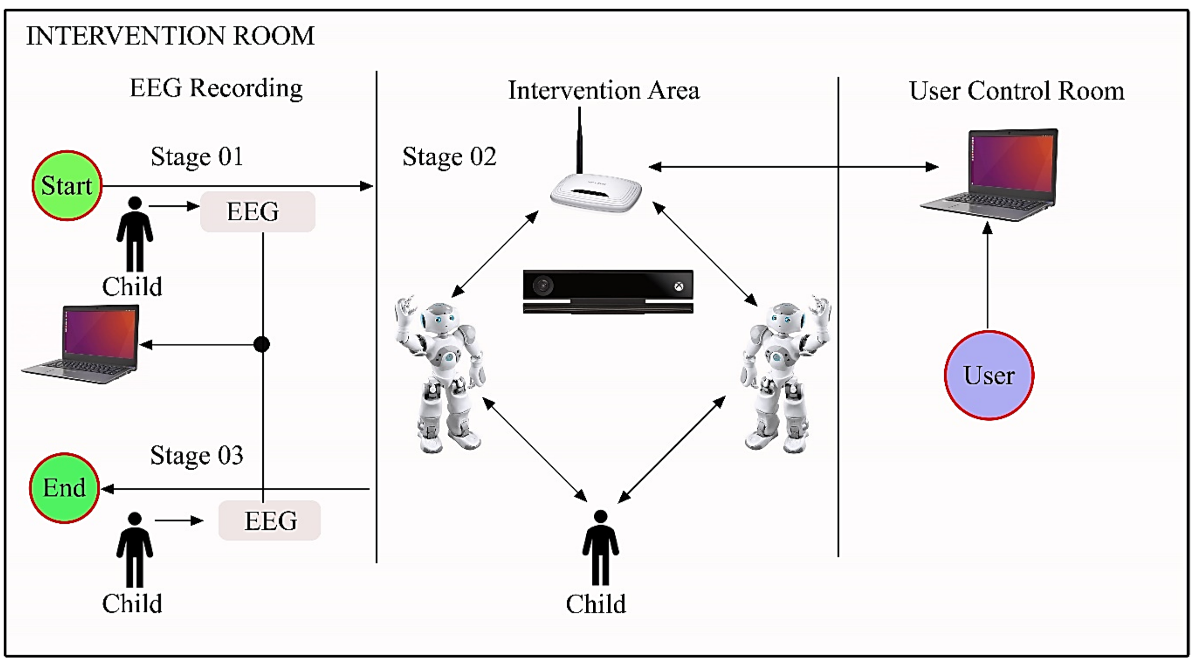

Figure 2.4: Intervention sequence and setup

During the intervention, we are noticing that how faster the joint attention of ASD child shifts between two NAO robots placed one meter away from child and one meter apart from each other as well, while Kinect V2 is present between them. Initially reinforcement stimuli are not given, but with the passage of time, reinforcement stimuli module starts, and they are given in least to most effective (LTM) order which is the base of assessment of sensitivity of child towards different types of reinforcement stimuli.

2.1.5 Algorithm / Pseudo code

Robot_Action_List =
["Visual", "Visual + Speech", "Visual + Speech + Motion"]
Initialization: n=1, Count=0, Index=1;
Load PQ (form Subject.xlsx) ***OR*** PQ = [] (First Time)
[Value, Index] = ***Max*** (PQ)
Step 01:
RA(n)=***Robot_Action*** (Robot_Action_List (Index))
RB(n)=***Robot_Behavior*** (RA(n))
RESP(n)=***Participant_Joint_Attention*** ();
IF(RESP(n) == ExpResp)
    Reward
    INSERT (PQ, RESP(n), Index)
    GO TO STEP03
Step 02:
    Index=***Next_Robot_Action*** (RESP(n), PQ)
    n++;
    Go to step 01
Step 03:
Write (***SORT***(PQ), Subject.xlsx) & Termination

<u>Function's description</u>

I. ***Load PQ:*** Load's Priority Queue List
II. ***Max:*** Returning max value.
III. ***Robot_Action:*** Gives action details to robot to be performed.
IV. ***Robot_Behavior:*** Represents the current behavior of robot
V. ***Participant_Joint_Attention:*** Noticing and evaluating joint attention of subject
VI. ***INSERT:*** Inserting current response and index to PQ list.
VII. ***Next_Robot_Action:*** Defining the action of next robot to be handled

We have different libraries for different reinforcement stimulus. They are [V], [S] and [M]. via combining these, we get different stimuli ranging from least to most (LTM) effective. Here V, S, and M denote Visual, Speech and Motion respectively. Different combination of these libraries will have different effects e.g., only visual stimulus will be having less effect as compare to visual and speech stimulus. "Robot_Action_List" provides these different reinforcement stimuli. Starting from least effective stimulus, "Robot_Action ()" function gives a robot action while later on defines a particular robot's behavior based on robot's action using "Robot_Behavior ()" function. "Participant_Joint_Attention ()" is a gaze tracking module which captures the joint attention of ASD child and gives us current response "RESP(n)". Now there are two possible cases, either this "RESP(n)=ExpResp ()" or "RESP(n)! =ExpResp ()". If this will be, a reward will be given, and we proceed towards the termination. On the other hand, we move to step 02 where higher effective stimuli are selected and given.

"Robot_Action_List" is a list which consists of all types of reinforcement stimuli. The order of stimuli is set in such a way that it moves from least effective to most effective one (LTM). In initialization of pseudo code, it searches for "PQ", if it exists then it will be loaded otherwise default one will be loaded as an initial case. "Max" function returns the most effective stimulus existing in PQ.

2.1.5.1 Explanation of Pseudo code:

- In step 01, index is passed to "Robot_Action_List" which gives a robot action to be performed and hence "Robot_Behavior" defines a behavior of robot. This behavior is passed to "Participant_Joint_Attention ()" function which notes the joint attention and gives an associated response. If current response matches with expected response, then reward is given, and control is transferred to step 02. If current response is not the expected response, then this step is repeated till "Max_Limit" is reached. Data is recorded, and code terminates.
- In step 02, PQ is checked first, if all the stimuli have been ordered according to the performance of subject, then code terminates otherwise current response is given to "Next_Robot_Action ()" function and step 01 is repeated till PQ is filled or any condition is met in step 01.
- In step 03, code terminates after saving the PQ list in sorted manner in an excel file. "Max_Limit" is also used to represent maximum limit on number of tries that have been done and still did not get expected response.

2.1.6 Finite State Machine of Joint Attention Measurement and Improvement System

Finite State Machine (FSM) are useful for representing system's flow of control. They are also used to visually define the states of system under specific input signals. Our system's FMS is shown in figure 2.5, presenting an intervention which can be used as joint attention improvement of ASD child.

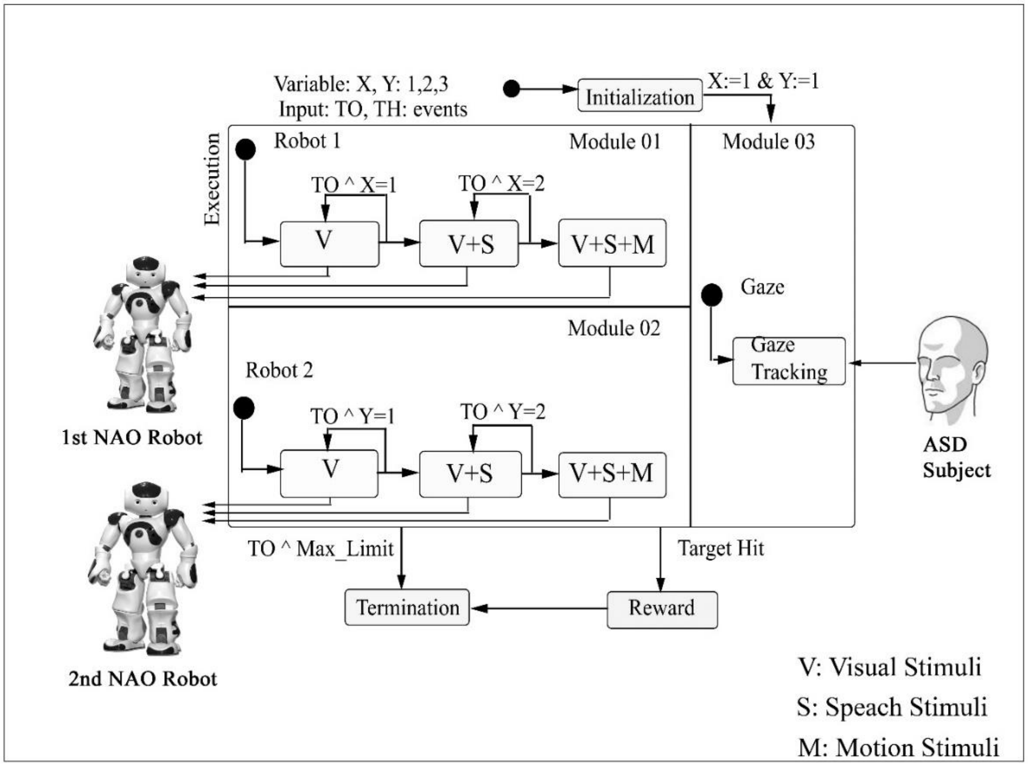

Figure 2.5: Finite state machine diagram of joint attention measurement and improvement system

There are total four states in first level. They are:

$$H_1 = [Initialization, Execution, Reward, and\ termination] \quad (1)$$

An XOR operation is being performed on different levels of all states. The aim of utilizing XOR operation is: it gives output equal to one if any of the bit is high. Output is zero for all those cases where all bits are identical. So, at hierarchy level one, our system's XOR function will be:

$$H_1 Output = (Initialization \otimes Execution \otimes Reward \otimes Termination) \quad (2)$$

At second hierarchy level, we have three different modules which are running in parallel to each other independently. They are: module 01, module 02, and module 03. Module 01 and 02 are further divided into three other states which are controlling reinforcement stimuli. While module 03 is gaze analysis module. So, at hierarchy level two, our system's XOR function will be:

$$H_2\ Output = [V \otimes V + S \otimes V + S + M] \quad (3)$$

These alphabets stand for:

V: only visual reinforcement stimuli

V+S: not only visual but speech reinforcement stimuli as well.

V+S+M: all reinforcement stimuli

This arrangement of reinforcement stimuli is based on least to most effective reinforcement stimuli. Visual stimuli are least effective while a combination of visual, speech and motion-based reinforcement stimuli will be most effective (LTM model).

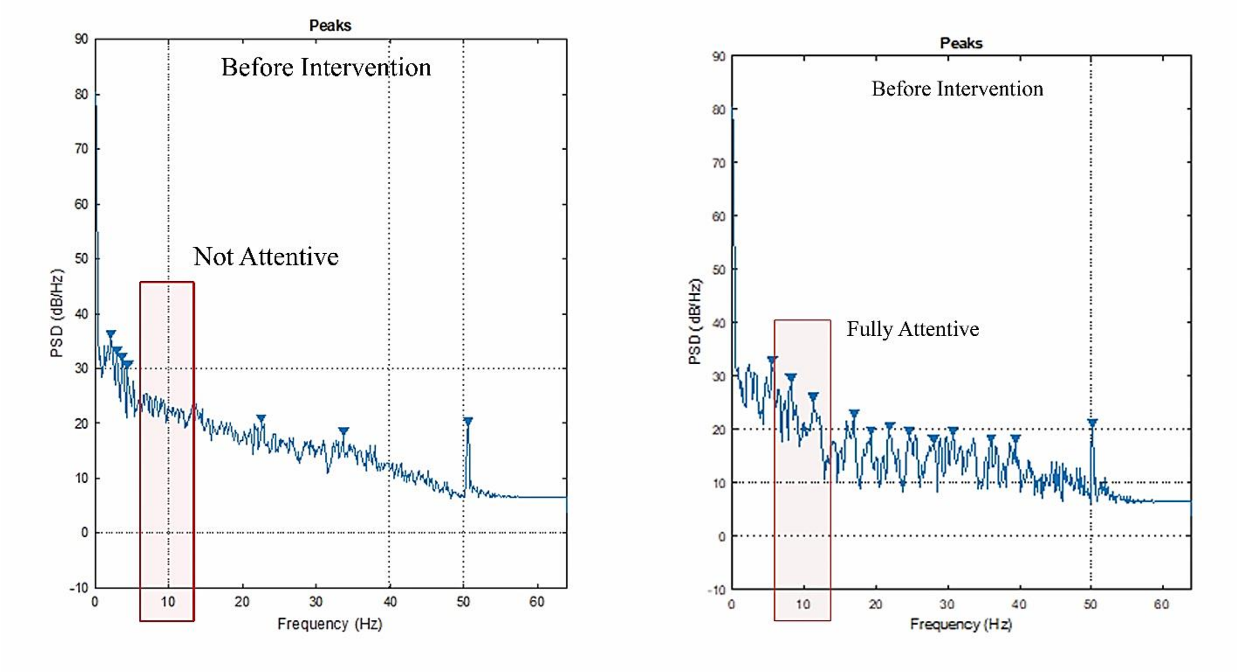

Figure 2.6: PSD of EEG signals of a subject, before and after intervention

This state machine is utilizing three variables: X, Y, and Max_Limit along with two events: TO (time out) and TH (target hit). "X" and "Y" variables' values range from 1 to 3 only, where "X" deals with robot one's second hierarchy level states and "Y" deals with robot two's second hierarchy level states. "Max_Limit" variable is set to 3 i.e., maximum we are trying any intervention three times if it is being failed. "TO" is an event which occurs only if we are not getting any response till specified seconds. Here its value is equal to 10 seconds. While "TH" is another event which occurs only if current response of ASD child matches with expected response and we give reward to child via waving hand and saying, "good job! You tried very well".

2.1.7 Cognitive State of Brain (pre and post intervention)

Assessment of cognitive state of brain of ASD child pre and post intervention was included to detect the change in state of brain due to intervention. During the assessment of cognitive state of brain, child is asked to count or speak English alphabets. These EEG recordings are lasting till two minutes. For recording of EEG signals, we used Emotive EPOC EEG neuroheadset, figure 2.7.

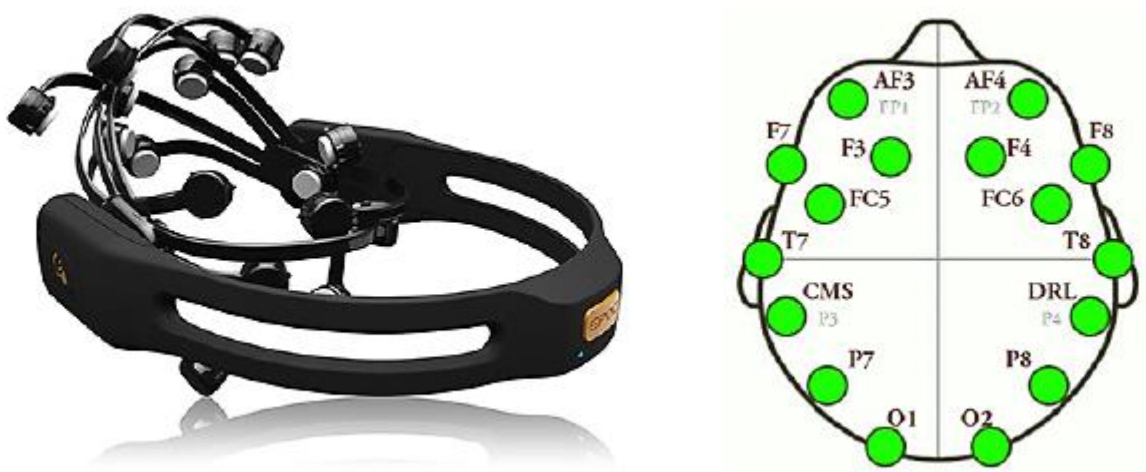

Figure 2.7: Emotive EPOC EEG neuroheadset

For the assessment of attention's information from EEG readings, we focus on frontal channels of neuroheadset. They are: AF3, AF4, F3, F4, F7, F8, and O1, and O2. After preprocessing, spatial averaging is done on these channels' signals and then Welch's PSD spectrum is plotted. For checking attention of ASD child pre and post intervention, we search for peaks with in alpha waves of brain which ranges from 5 Hz to 12 Hz. If we find peak(s) then child was attentive otherwise he / she may follow the command, but he / she was mentally absent at that instant.

2.1.8 Assessed parameters of Joint attention measurement and Improvement system

Joint attention measurement and improvement system can record different parameters. These parameters, along with their detailed description, are given in table 2-1, below.

Table 2-1 Parameters recorded by multi humanoid robot based joint attention measurement and improvement system

Sr.#	Parameter	Description	Sensor / Technique
1	N_e	Total number of eye contacts recorded by NAO robots	NAO robots' cameras
2	t_e	Array of time of each eye contact with NAO robots	-do-
3	L_{e_1}	Latency of first eye contact with any of NAO robot	-do-
4	N_{fn}	Number of eye contacts with first NAO robot	-do-
5	N_{sn}	Number of eye contacts with second NAO robot	-do-
6	t_{Max}	Maximum eye contact duration	Mathematically calculated
7	t_{Min}	Minimum eye contact duration	-do-
8	t_{Avg}	Average eye contact duration	-do-
9	t_i	Total time for intervention	-do-
10	d	Vector of delays between adjacent eye contacts	-do-
11	t	Time series vector	-do-
12	α	Vector of deviation angles	Kinect
13	p	Percentage of accurately captured reinforcement stimuli	Mathematically calculated
14	N_k	Total number of attention diversion recorded by Kinect	Kinect
15	N_{kl}	Total number of attention diversion towards left robot, recorded by Kinect	Kinect
16	N_{kr}	Total number of attention diversion towards right robot, recorded by Kinect	Kinect
17	N_{ri}	Number of accurately captured reinforcement stimuli	NAO Robots
18	N_{mri}	Numbered of missed reinforcement stimuli	NAO Robots

2.2 Multi Humanoid robots based imitation system actuated by joint attention of ASD child (PART B)

2.2.1 Architecture Explanation

Consider figure 2.8, there are three major modules, NAO Robot 1, NAO Robot 2, Computer along with ASD child and a network router. In computer block, we have two TCP servers, denoted by $S_1$and S_2. In each NAO Robot, we have two different modules, eye contact measuring module and action module. Both modules are thread safe and running in parallel fashion. These modules are integrated with TCP clients, which are represented by C_{ij}. Note down the color-coding scheme or numbering scheme in figure, which illustrates the connection and communication between these TCP clients and TCP servers. These communication details are as under:

$\boldsymbol{S_i}$**:** Where i is server number.

$\boldsymbol{C_{ij}}$**:** Where i is server number, to whom this client must be connected, and j is client number connected to server i.

So,

$\boldsymbol{S_1}$**:** TCP Server one, controlling action modules running on both NAO robots.

$\boldsymbol{S_2}$**:** TCP Server two, controlling eye contact detection modules running on both NAO robots.

$\boldsymbol{C_{11}}$**:** First TCP client of Server one (integrated with actions module), running on NAO one.

$\boldsymbol{C_{12}}$**:** Second TCP client of Server one (integrated with actions module), running on NAO two.

$\boldsymbol{C_{21}}$**:** First TCP client of Server two (integrated with eye contact module), running on NAO one.

$\boldsymbol{C_{22}}$**:** Second TCP client of Server two (integrated with eye contact module), running on NAO two.

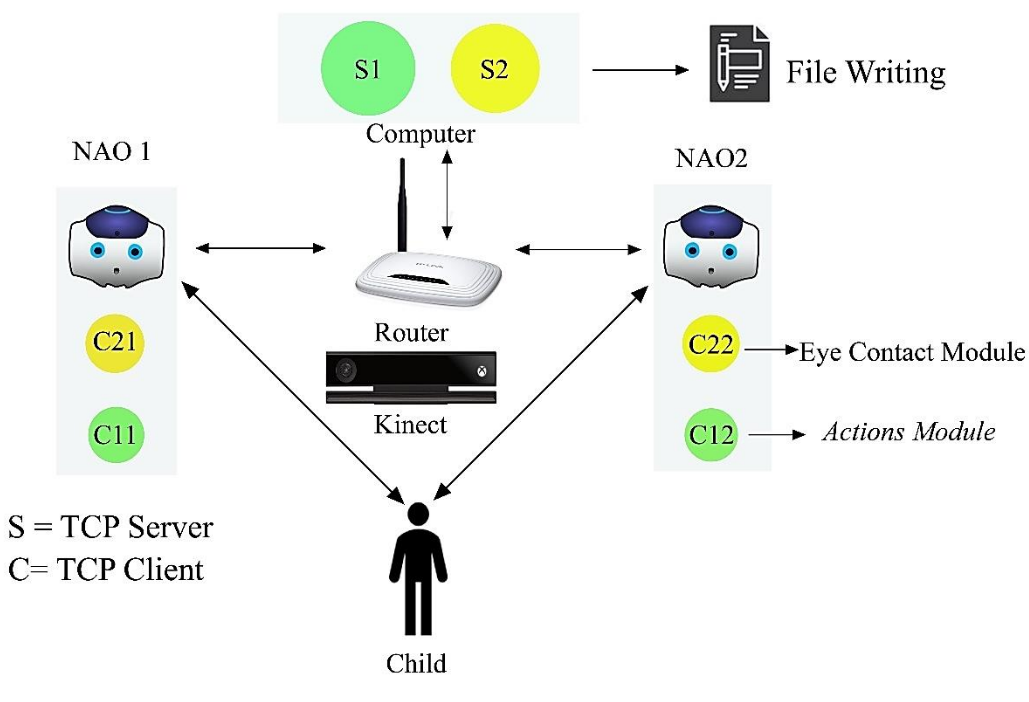

Figure 2.8: Architecture of imitation system actuated by joint attention of ASD child

Both servers are independently running on computer and controlling their corresponding modules. They are writing information to their respective text files for off line processing. All these clients and servers are communicating and sharing information with each other through a wireless network which supports full duplex communication. We introduced Kinect V2 sensor in whole setup for noticing the diversion of attention, and imitation accuracy of ASD child.

2.2.2 Networking information

Figure 2.9 gives all of networking information of whole system of intervention. We used static IPs for NAO robots along with TCP servers. Network IPs of TCP servers and NAO robots are different. TCP servers' IPs are same as of computer's static IP address. This network address belongs to class A of networking address range. Despite of having same IP addresses for different servers, information and data were remaining separate from each other because ports of communication for both servers were different. You can set network address range and IPs according to your own ease but keep this thing in your mind that you must have to declare / assign static IP addresses to these devices for proper working of this network.

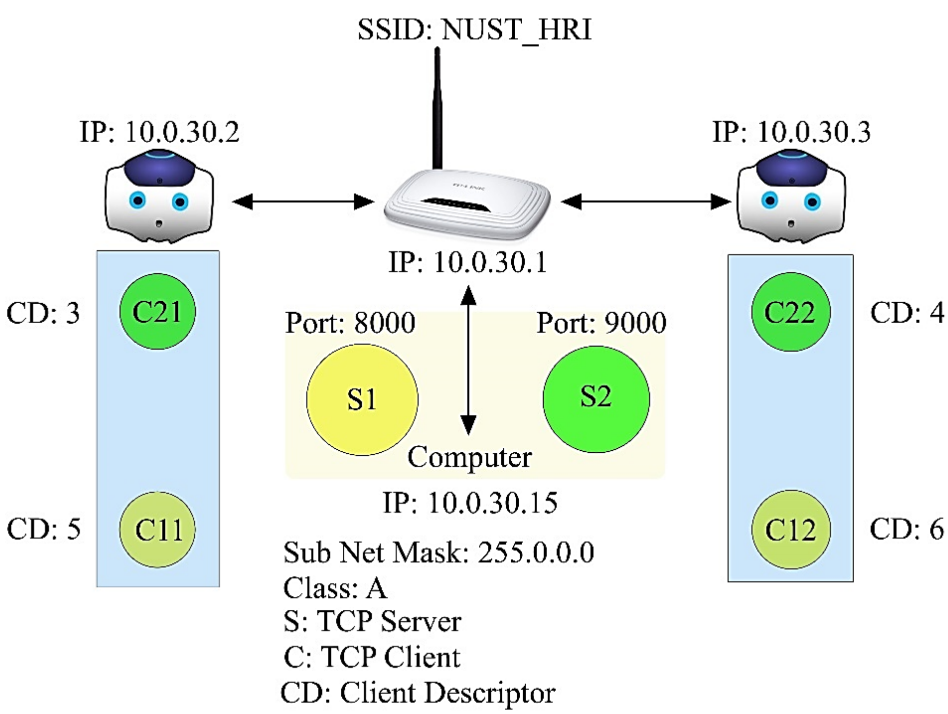

Figure 2.9: Networking details of multi humanoid robot based imitation system actuated by joint attention of ASD Child.

CDs are client descriptors which are allotted on run time process. NAO's OS default communication port is 9559. You must ensure that none of your server is using this channel for communication because it will not work. This channel is reserved for communication with NAO robot. Moreover, try to use higher port for communication, start from 5000 or 6000. Higher port numbers are usually vacant in a network and hence reduces the chance of communication interference.

2.2.3 Intervention sequence and setup hierarchy

Consider figure 2.10 which represents the intervention sequence and complete setup of therapy. Intervention room is divided into three different parts via two partitions. Extreme left part is reserved for accessing cognitive state of brain of ASD child (Recording EEG) before and after the completion of each therapeutic intervention. While extreme right part is reserved for user, controlling NAO robots and other sensory devices. The middle part is reserved for therapeutic intervention of ASD child. There are total three stages through which an ASD child will pass. Initially he / she will report in extreme left part, for the assessment of cognitive state of brain.

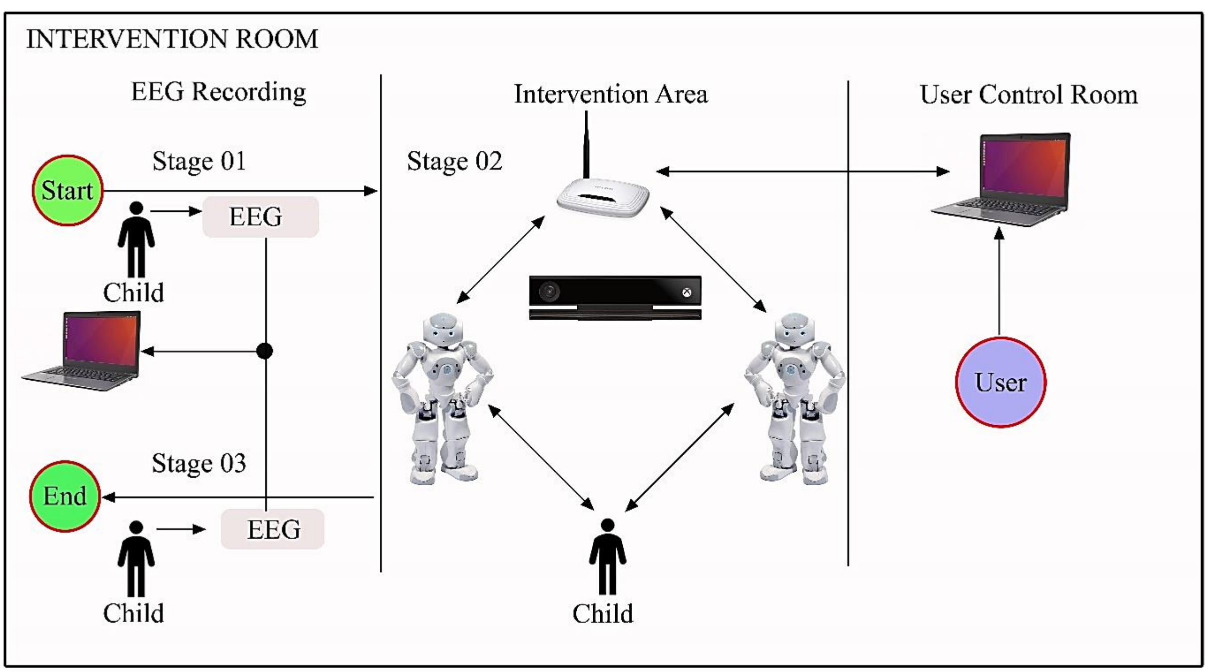

Figure 2.10: Intervention sequence and setup

Latterly, he / she will be sent in to intervention area where the intervention takes place and after the completion of therapeutic intervention, he / she will be sent to left part (EEG recording area) for the assessment of cognitive state of brain so pre and post intervention steps are, assessment of cognitive state of brain of ASD child. During the intervention, we are noticing that how faster the joint attention of ASD child shifts between two NAO robots placed one meter away from child and one meter apart from each other as well, while Kinect V2 is present between them. Initially reinforcement stimuli are not given, but with the passage of time, reinforcement stimuli module starts, and they are given in least to most effective (LTM) order which is the base of assessment of sensitivity of child towards different types of reinforcement stimuli.

2.2.4 Algorithm / Pseudo Code

Robot_Action_List= [“Move Forward”, “Move Backward”, “Raise Hands”, “Hands Down”]

Initialization: n=1, Count=0, t=10;
Load PQ (form Subject.xlsx) ***OR*** PQ = [] (First Time)
[Value, Index] = ***Max*** (PQ)
Step 01:
RESP=***Participant_Joint_Attention*** ();
IF (RESP => ExpResp)
RA=***Robot_Action*** (Robot_Action_List(n))
RB=***Robot_Behavior*** (RA)
Delay (t)
n++
RA=***Robot_Action*** (Robot_Action_List (n))
RB=***Robot_Behavior*** (RA)
Reward
Go to step 02
ELSE
Step 02:
Termination

Function’s description

X. ***Load PQ ():*** load’s Priority Queue List
XI. ***Max ():*** Giving the high priority index
XII. ***Robot_Action ():*** Gives action details to robot to be performed.
XIII. ***Robot_Behavior ():*** Represents the current behavior of robot
XIV. ***Participant_Joint_Attention():*** Noticing and evaluating joint attention of subject

We have one library which is “Robot_Action_List” which describes the action list of both robots. At the initialization of algorithm, priority queue list, named PQ, is loaded which tells us about the last robot’s action which has been imitated by child successfully. Then “Participant_Joint_Attention ()” function, gaze tracking, is used to capture the joint attention of ASD child which gives us the current response of child in “RESP”. Now there are two conditions, either current response will match with expected response “ExpResp” or it will not. If it matches, “Robot_Action ()” function will define action and “Robot_Behavior ()” will give behavior of robot defined by that robot’s action. “Delay ()” gives chance to child to imitation the action performed by robot. Again, robot’s action and robot behavior are generated via incrementing “n” which leads us towards different robot’s actions and behaviors and then code terminates.

2.2.4.1 Explanation of Pseudo code:

- In initialization, different variables and PQ List is loaded. PQ list tells us about last successive action of robot which had been followed by ASD child.
- In step 01, ASD child’s joint attention is captured with gaze tracking module and its current response is compared with expected response. If current response matches with expected response, then robot performs action which must be imitated by child, and after some delay, another action is performed. If actions are performed by child successfully, a reward is given.
- In step 02, program terminates.

2.2.5 Finite State Machine of multi humanoid robots based Imitation system actuated by Joint Attention of ASD child

Finite State Machine (FSM) are useful for representing system’s flow of control. They are also used to visually define the state of system under specific input signals. Our system’s FMS is shown in figure 2.11. There are total four states in first level. They are:

$$H_1 = [Initialization, Execution, Reward, and\ termination] \qquad (4)$$

An XOR operation is being performed on different levels of all states. The aim of utilizing XOR operation is: it gives output equal to one if any of the bit is high. Output is zero for all those cases where all bits are identical. So, at hierarchy level one, our system’s XOR function will be:

$$H_1 Output = (Initialization \otimes Execution \otimes Reward\ \otimes Termination) \qquad (5)$$

At second hierarchy level, we have three different modules which are running in parallel to each other independently. They are: module 01, module 02, and module 03. Module 01 and 02 are further divided into two other states which are controlling robots’ action. While module 03, is gaze analysis module. So, at hierarchy level two, our system’s XOR function will be:

$$H_2\ Output\_Robot\_one = [Forward \otimes Backward] \quad (6)$$
$$H_2\ Output\_Robot\_two = [Raise\ hands \otimes Hands\ down] \quad (7)$$

These alphabets stand for:

Forward: action, moving forward.

Backward: action, moving backward.

Raise Hands: action, raising hands.

Hands Down: action, hands down.

Imitation module is adaptive with respective to gaze of child. Actuations of robots are dependent upon the eye contact of child. If child maintains an eye contact, for 5 seconds, with robot, he will be actuated otherwise no actuation will occur.

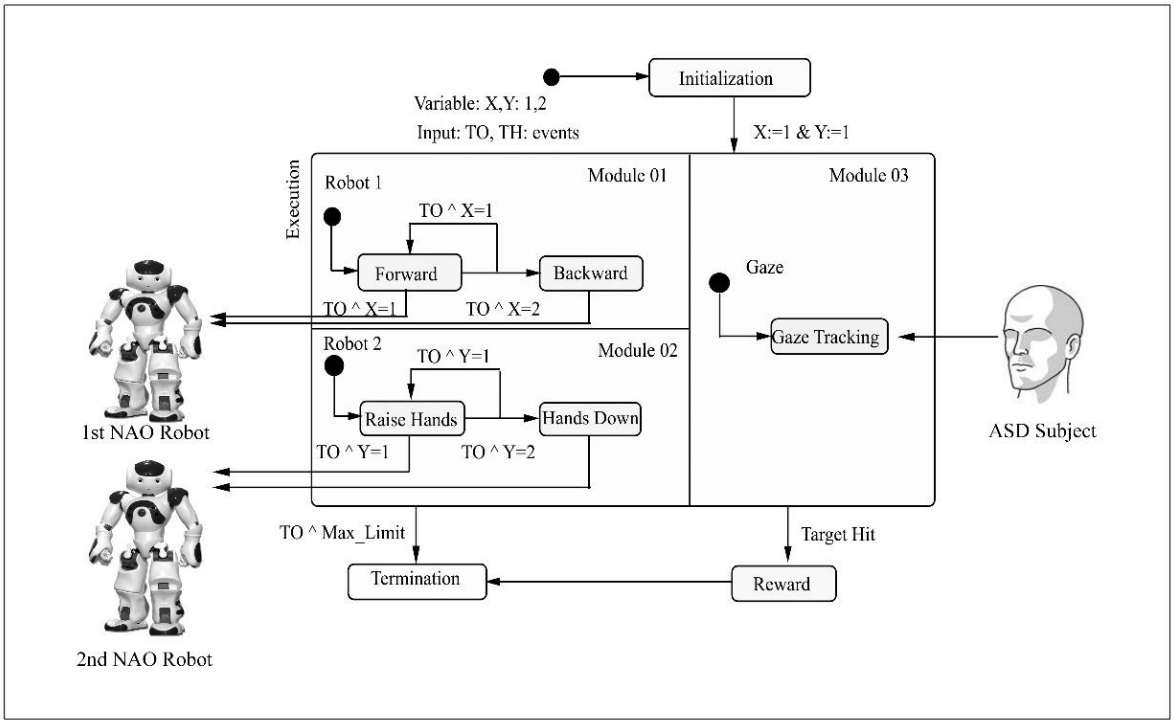

Figure 2.11: Finite State Machine of imitation system actuated by joint attention of ASD child

This state machine is utilizing three variables: X, Y, and Max_Limit along with two events: TO (time out) and TH (target hit). "X" and "Y" variables' values range from 1 to 2 only, where "X" deals with robot one's second hierarchy level states and "Y" deals with robot two's second hierarchy level states. "Max_Limit" variable is set to 3 i.e., maximum we are trying any intervention three times if it is being failed. "TO" is an event which occurs only if we are not getting any response till specified seconds. Here its value is equal to 10 seconds. While “TH” is another event which occurs only if current response of ASD child matches with expected response and we give reward to child via waving hand and saying, “good job! You tried very well”.

2.2.6 Cognitive State of Brain (pre and post intervention)

Assessment of cognitive state of brain of ASD child pre and post intervention was included to detect the change in the state of brain due to intervention. During the assessment of cognitive state of brain, child is asked to either count or speak English alphabets. These EEG recordings are lasting till two minutes. For recording of EEG signals, we used Emotive EPOC EEG neuroheadset, figure 2.7.

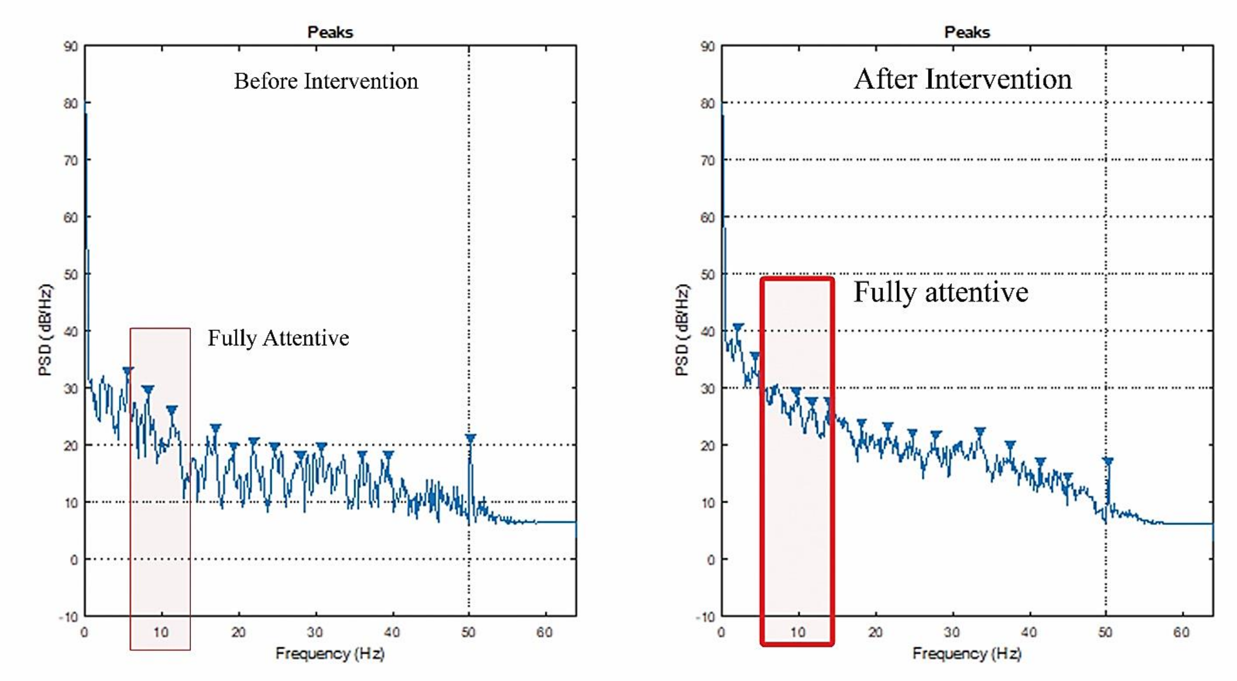

Figure 2.12: PSD of EEG signals of a subject, before and after intervention

Figure 2.12 shows the result, PSD plot, of EEG of a subject before and after the intervention. You can clearly see different peaks which were being captured over whole spectrum of brain’s signal. We are only focusing on alpha band, ranging from 5 Hz to 12 Hz, showed by rectangular box. For the assessment of attention’s information from EEG readings, we focus on frontal channels of neuroheadset. They are: AF3, AF4, F3, F4, F7, F8, and O1, and O2. After preprocessing, spatial averaging is done on these channels’ signals and then Welch’s

PSD spectrum is plotted. For checking attention of ASD child pre and post intervention, we search for peaks with in alpha waves of brain which ranges from 5 Hz to 12 Hz. If we find peak(s) then child was attentive otherwise he / she may follow the command, but he / she was mentally absent at that instant. EEG classification scheme is presented in figure 2.14.

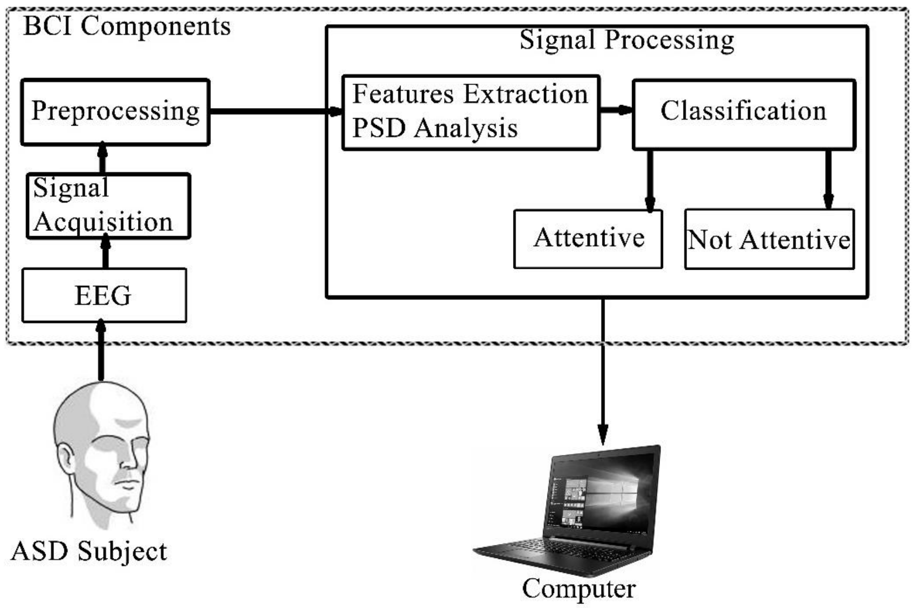

Figure 2.13: EEG classification scheme

CHAPTER 03

EXPERIMENTAL RESULTS

Results section of thesis have been divided into three different parts. First part describes different results related to first intervention, i.e., multi humanoid robot based joint attention measurement and improvement system with reinforcement stimuli, second part describes different results related to second intervention, multi humanoid robot based joint attention system actuated by joint attention of ASD children, and third part describes cognitive state of brain of ASD children in both interventions, before and after.

3.1 ASD subjects' details

For conducting these experiments, we used thirteen different ASD subjects. Each subject had been passed from eight different experiments in each intervention. Their details: regarding age, place on spectrum, autism case category, and childhood autism rating scale (CARS) score are given in appendix A. Experimentation period was six months long and each subject was having two trials per week.

3.2 Joint attention measurement and improvement system (Part A)

As previously stated, joint attention is most important social skill in human being. It helps a lot in keeping an individual fully attentive and aware of his / her surrounding environment. Figure 3.1 shows eye contacts versus experiments plot of each subject. Each reading has been averaged and total eight experiments were conducted for each subject. Graph shows that performance of each subject is increasing as we proceed in number of experiments as the vertical spread of data points along y-axis is being increased. Eye contact time for each experiment is basically the average of all eye contacts duration which were made by subject with robots. The increasing value of eye contact over the experiment shows that subject is taking more interest in robots. These reading includes reinforcement stimuli as well which were also the cause of capturing attention of subject. In figure 3.2, eye contact delay is plotted against number of experiments. With eye contact delay, we mean that when a reinforcement stimulus was given and after how long child paid attention. Each point is an average of all the delays which occurred in immediately capturing different stimuli. The decreasing trend of graph is showing that joint attention of child is being improved over the experiments, means the delay is being reduced as the vertical spread of data points along y-axis is being decreased.

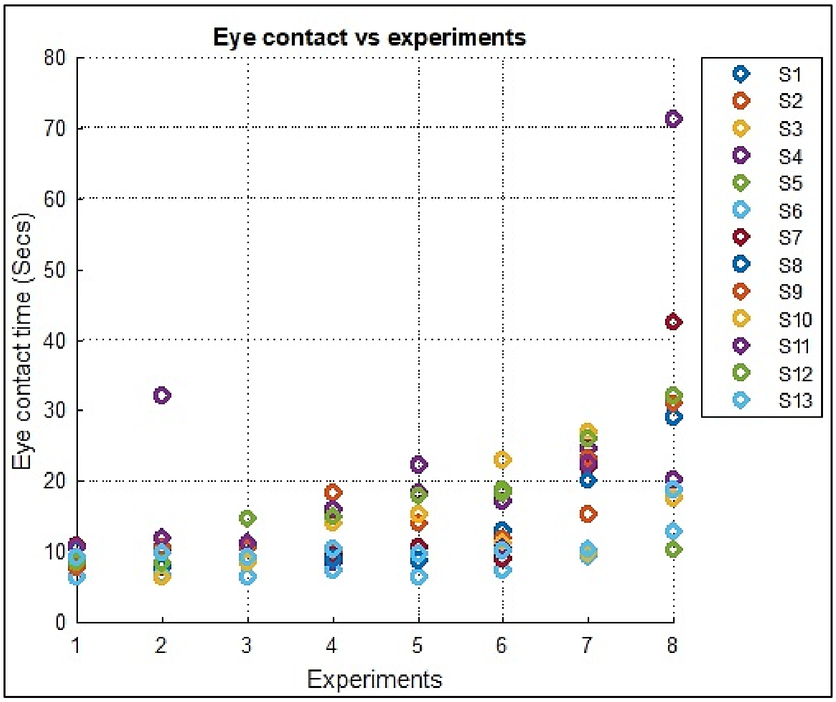

Figure 3.1: Eye contact duration versus experiments

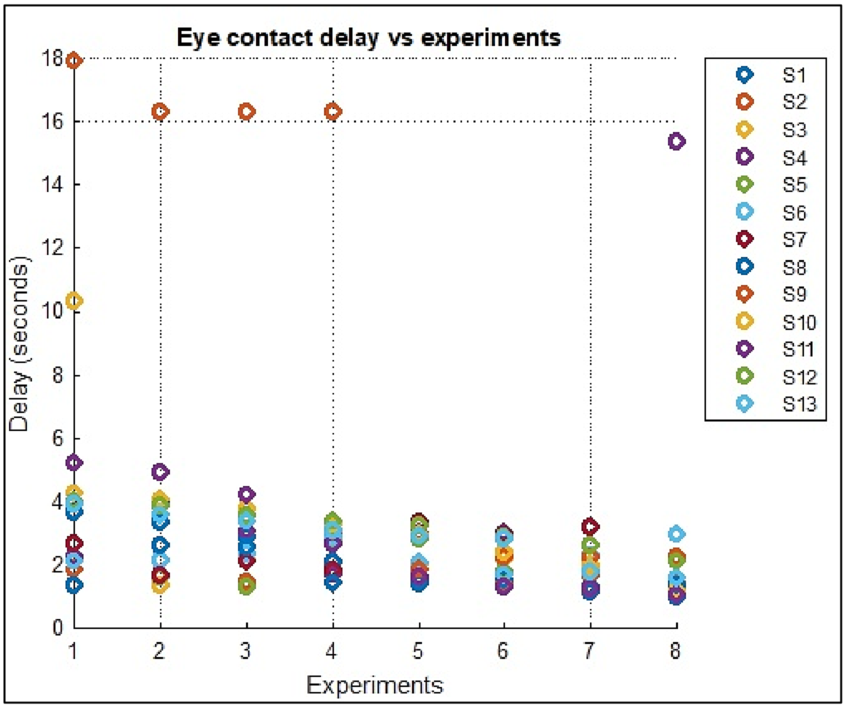

Figure 3.2: Delay in establishing eye contact on providing stimuli versus experiments

3.2.1 Standard deviation mean and error bar

Figure 3.3 is an error bar graph of three different reinforcement stimuli average success rate of all subjects, thirteen in our case. Statistical parameters are: standard deviation = 2.0791; Mean value = 68.9530; Coefficient of variation = 0.0302.

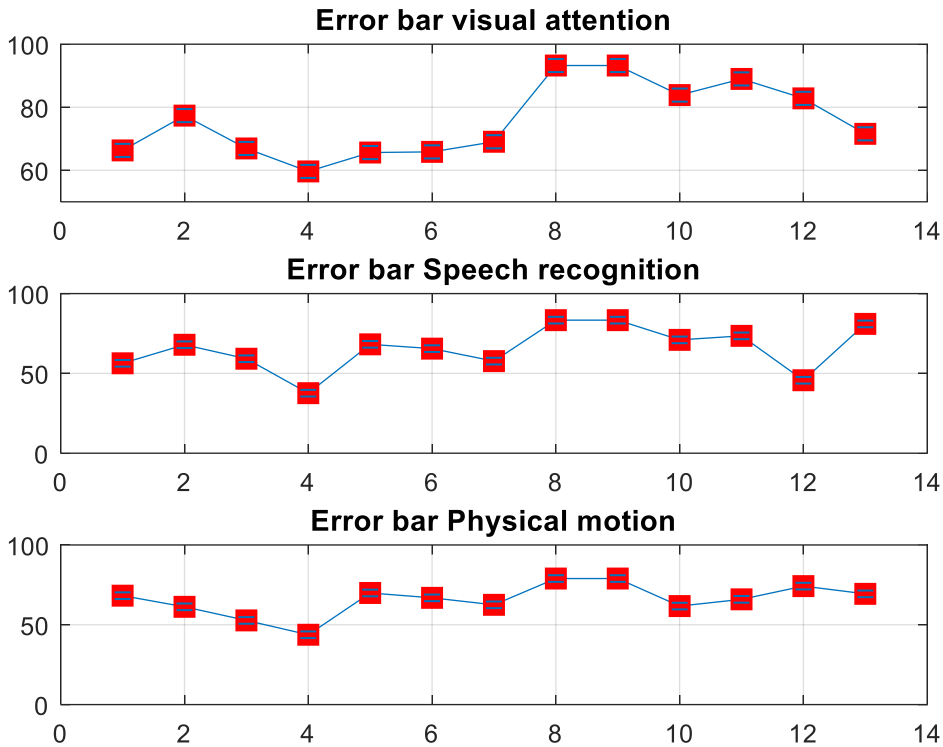

Figure 3.3: Error bar graph of all subjects

Here x-axis shows the number of experiments, while y-axis shows the mean value of success of each subject. These three error bar graphs are conveying some useful information regarding sensitivity of all subjects towards different reinforcement stimuli. If we talk about the overall effectiveness of these reinforcement stimuli, then we can say that physical motion-based stimuli scored higher, but this is not true in few subjects. For example, subject 08 was more sensitive towards visual attention-based reinforcement stimulus as compared to speech recognition or physical motion-based stimuli.

Referring to figure 3.4, all six reinforcement stimuli are plotted for each subject representing the average percentage of success and showing the subject was deviated towards which stimulus more? Figure 3.5 is another graph which is more general as compare to figure 3.4. In figure 3.5, we plotted only three distinguished types of reinforcement stimuli's success rates of each subject. Note that, visual attention is a combination of Blink and Rasta stimuli, speech recognition is a combination of Hi and Hello stimuli, and physical actions is a combination of standing & waving and sitting reinforcement stimuli.

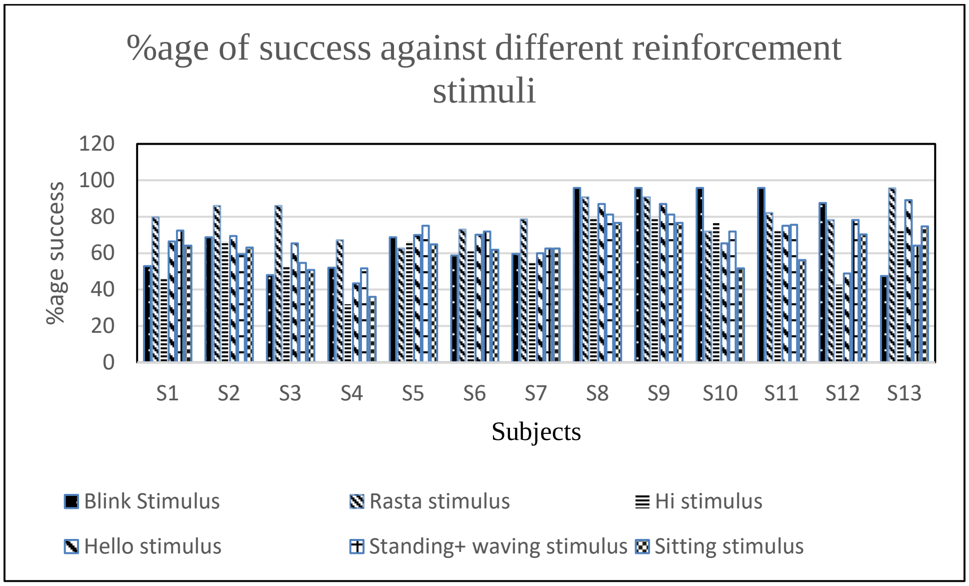

Figure 3.4: Success percentage of each subject against each reinforcement stimuli

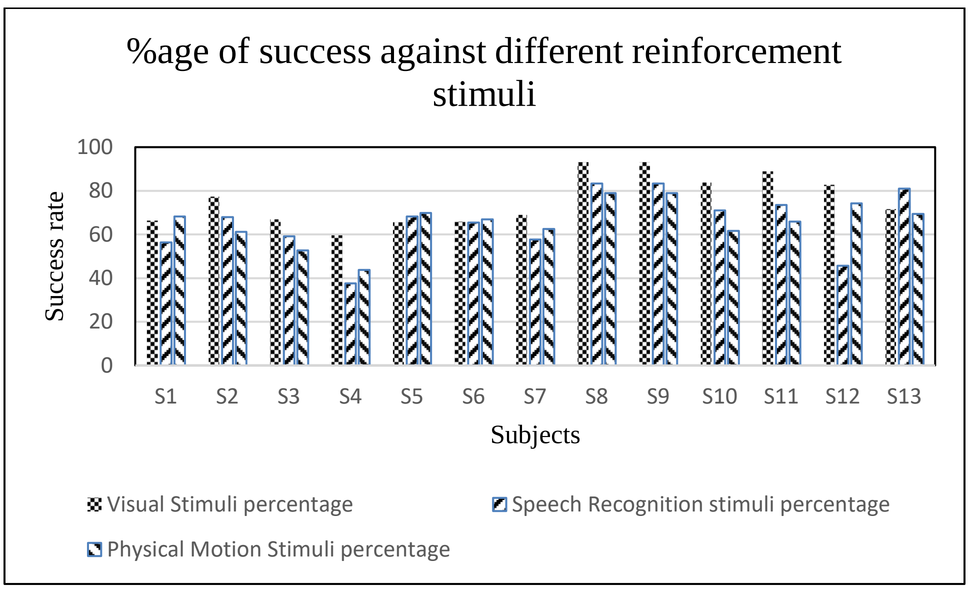

Figure 3.5: Success percentage of all subjects against different types of reinforcement stimuli

3.2.2 Actions of robots versus joint attention of subject

In our joint attention measurement and improvement system with reinforcement stimuli both robots are giving different reinforcement stimuli at different times with a delay of five seconds and simultaneously noticing the joint attention of subject as well. Figure 3.6 is representing the actions of robots over time along with the information of joint attention of subject. X-axis represents time, in seconds, while y-axis represents actions and joint attention towards both robots. Blink, Rasta, Hi, Hello, Standing and Waving arm, and Sitting are reinforcement stimuli while NAO 1 and NAO 2 are robots to whom attention is being paid right now. This graph represents that, at which instant which robot gave reinforcement stimuli and where the joint attention of subject was?

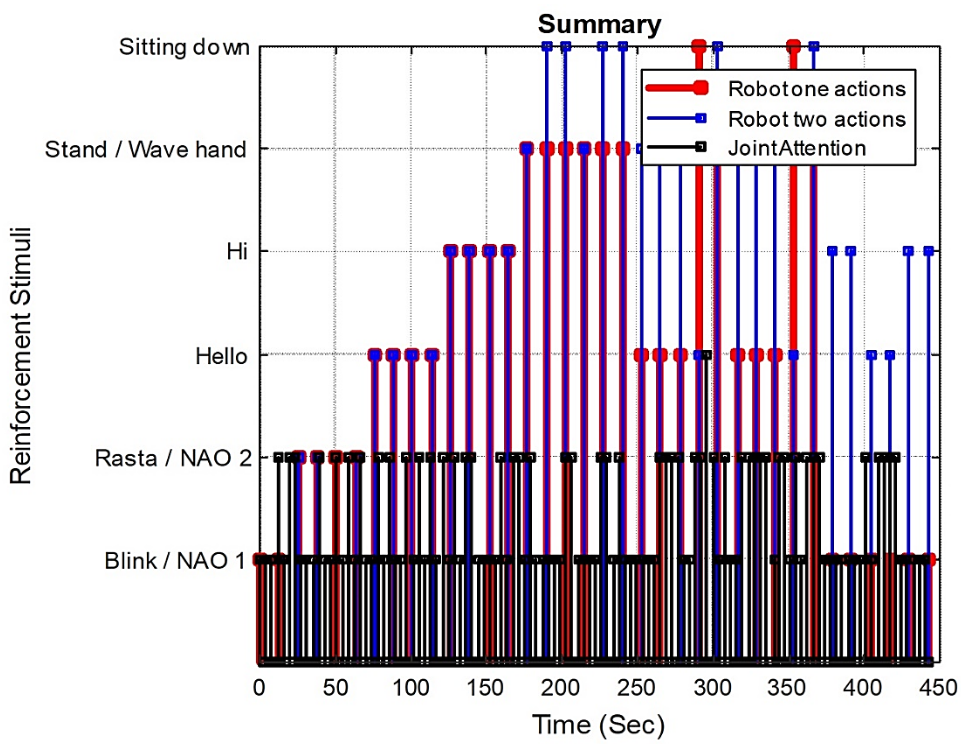

Figure 3.6: Time versus reinforcement stimuli from robots along with joint attention of a subject

3.2.3 Sensitivity of subject towards different reinforcement stimuli

It might possible that subject is not paying attention towards robots, then in such cases, we must introduce reinforcements stimuli. These reinforcement stimuli are divided into three categories. They are visual attention, speech recognition and physical movements. Near us, these different reinforcement stimuli have different impacts on subject and will be having different tendency of capturing the joint attention of subject. Among these, we are considering physical movement stimuli as most effective one, while visual attention is being considered least effective one. Obviously, this will not be true for each subject due his / her own behavior but in general, it is acceptable. Figure 3.7 is a graph which is showing the sensitivity of different subjects with respect to these reinforcement stimuli. Graph shows that subject 1 is more sensitive towards physical actions, while subject 2, subject 3 and subject 4 are more sensitive towards visual attention as compare to other reinforcement stimuli.

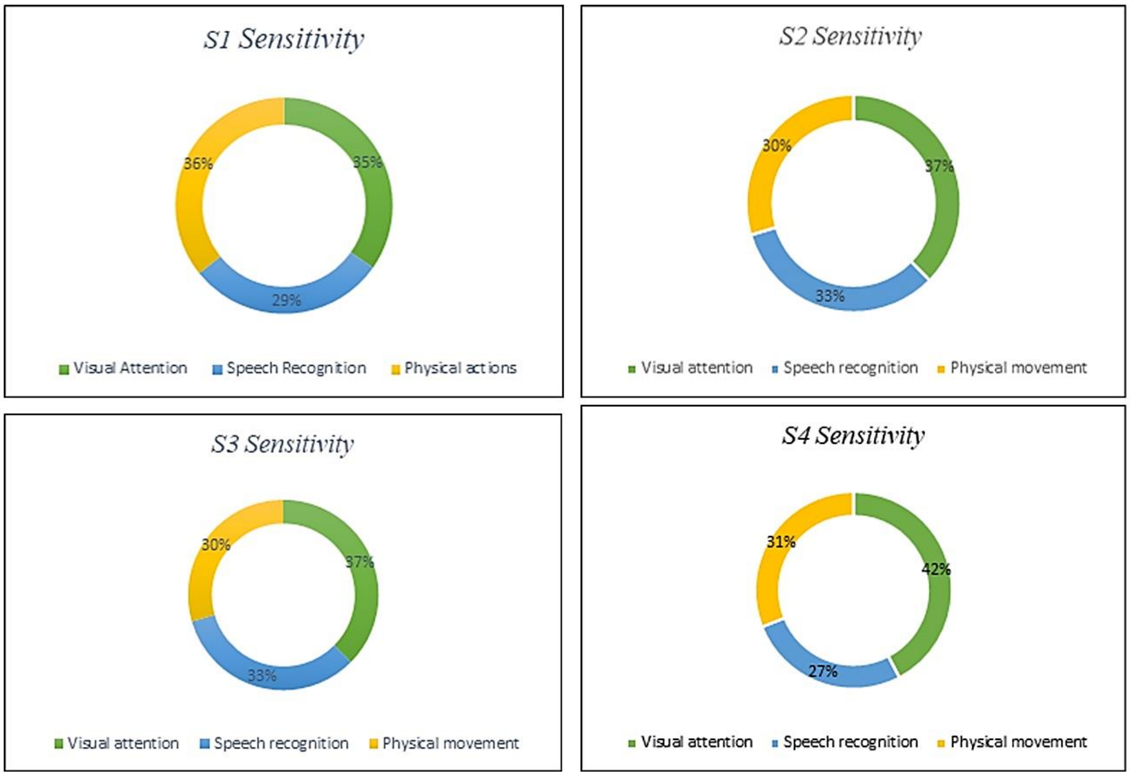

Figure 3.7: Sensitivity plot of different subjects with respective to reinforcement stimuli

3.2.4 Success rates over all experiments of a subject

Figure 3.8 shows success rate of different types of reinforcement stimuli which are plotted against eight different experiments of a subject. This figure is showing the general trend of these reinforcement stimuli over the experiments of a subject. These trends are showing fluctuations which are representing the interest of subject in intervention. These success rates are plotted based on number of hits of subjects. Here, number of hits are representing the accurately transferring of joint attention towards different reinforcement stimuli of both robots. Number of miss are counter to number of hits. X-axis is representing the experiments while y-axis is representing the average percentage of success related to different kinds of stimuli. Which stimulus is more effective for a subject? This can be answered using this plot as well via taking the average of all of these over eight experiments. There is another way to get the answer of same question, we can also consider the area under the curve, higher the area under the curve, higher will be the stimulus effectiveness and vice versa. This information will be a base line for us which can be used for next interventions to use those reinforcement stimuli which are more effective in capturing the attention of child.

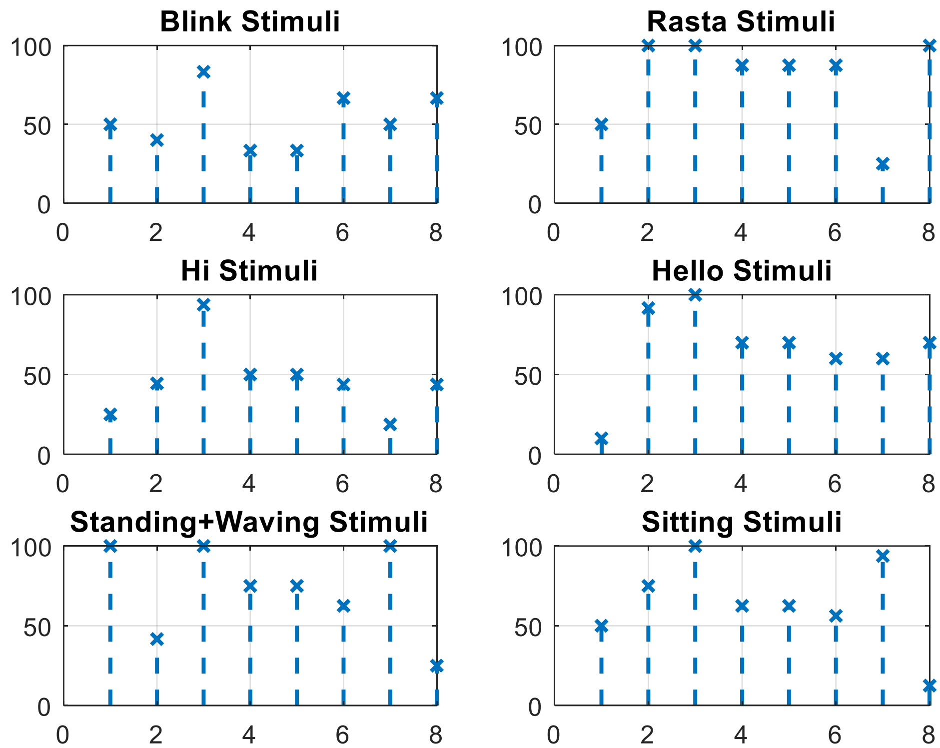

Figure 3.8: Success percentages of different reinforcement stimuli against each experiment of subject 01

3.2.5 Time given to each stimulus over the experiements

Consider the figure 3.9, where all experimental results of a subject are plotted. X-axis is indicating the number of experiments and y-axis is representing time given to each reinforcement stimuli in seconds. This plot is enough to tell that during the intervention, participant concentrated how much, and on which type of reinforcement stimuli? This is another way of getting the information of sensitivity and interestedness of subject. If the time, which is being spent in a reinforcement stimulus is greater than all other times of all other reinforcement stimuli, then this means that reinforcement stimuli was dominating in intervention.

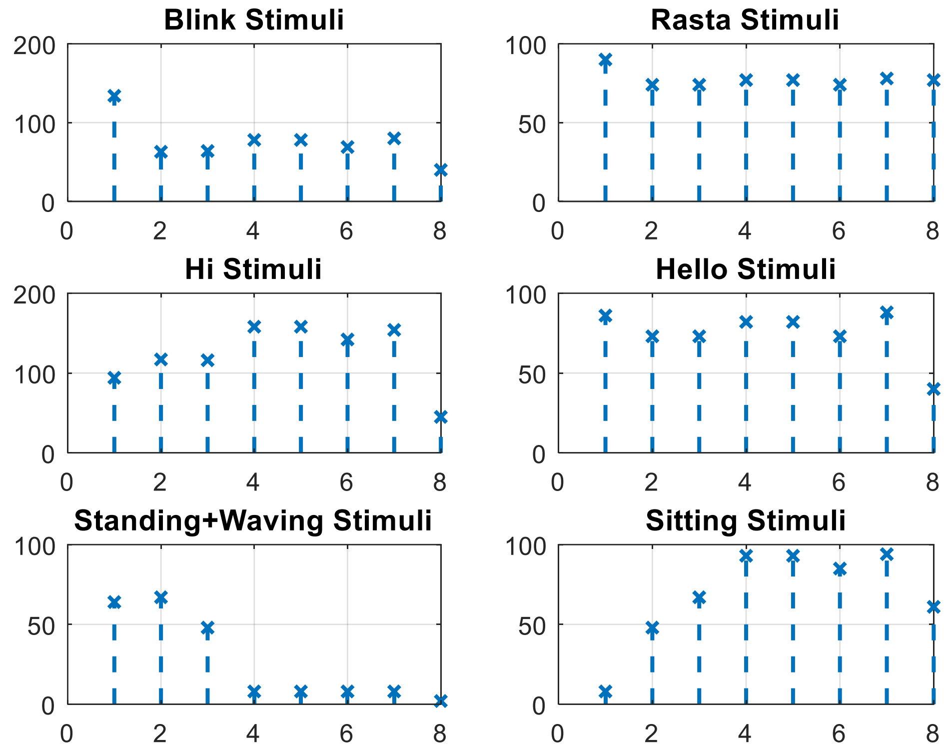

Figure 3.9: plots of time given to different reinforcement stimuli in different experiments by subject 01

3.2.6 Parameters recorded by joint attention measurement and improvement system

Designed joint attention measurement and improvement system can record multiple variables. These variables are providing different relevant details. Table 3-1 is providing different variables, along with their details, which are being recorded by joint attention system. Different sensors are also mentioned which were used to capture these variables' values. While table 3-2 is representing the actual average values, over eight experiments, of these variables for all subject. All readings of time are given in seconds.

3.2.7 Improvement in eye contact

Average eye contact durations of each subject in each experiment have been plotted in figure 3.11. All the subjects' readings showing an increasing trend except for subject 4 (S4). The non-increasing trend of S4 is due to having no interest in intervention. This is depicted by figure 3.17 where interest, before and after intervention, is measured. We can see that subject was having

Table 3-1 Different parameters measured by our designed system

Sr.	Variable	Description	Sensor used
1	N_e	Total number of eye contacts recorded by NAO robots	NAO robots' cameras
2	t_{max}	Maximum eye contact duration	Mathematically calculated
3	t_{min}	Minimum eye contact duration	-do-
4	t_{avg}	Average eye contact duration	-do-
5	N_{no}	Number of eye contacts with first NAO robot	-do-
6	N_{nt}	Number of eye contacts with second NAO robot	-do-
7	t_i	Total time for intervention	-do-
8	N_{ri}	Number of accurately captured reinforcement stimuli	NAO Robots
9	N_{mri}	Numbered of missed reinforcement stimuli	NAO Robots
10	N_k	Total number of attention diversion recorded by Kinect	Kinect V2

Table 3-2 Values of different parameters of all subjects, measured by our system

Subject	N_e	t_{max}	t_{min}	t_{avg}	N_{no}	N_{nt}	t_i	N_{ri}	N_{mri}	N_k
S1	104.12	10.62	0.75	2.742	59.50	44.625	445.00	39.37	26.25	97.25
S2	137.5	18.12	1.125	1.5298	85.875	51.625	408.87	45.62	21.12	66.00
S3	121.75	3.75	1.125	2.068	84.625	37.125	498.50	38.12	27.25	77.12
S4	56.375	0.875	0.125	0.3723	38.625	17.75	396.50	28.00	37.62	75.62
S5	114.85	2.00	0.1428	0.5454	74.571	40.285	409.14	42.857	21.14	46.71
S6	116.28	3.571	0.2857	1.1508	76.571	39.714	464.14	45.714	30.28	138.57
S7	111.2	0.857	0.1428	0.475	72.571	38.714	396.71	37.42	26.00	29.00
S8	206.5	1.00	0.00	0.3827	134.00	72.571	413.42	55.42	12.00	186.57
S9	53.57	2.428	0.7142	1.268	27.142	26.428	455.14	28.28	49.42	67.857
S10	57.42	4.428	0.4285	0.9514	31.571	25.857	244.28	39.14	18.00	66.571
S11	58.4	3.57	0.4285	1.1354	34.571	23.857	402.57	41.857	20.714	64.857
S12	57.37	1.00	0.125	0.2901	44.00	13.375	494.37	35.875	21.125	32.125
S13	90.125	7.125	0.875	1.8090	42.25	47.875	448.62	47.875	18.00	6.125

* All time readings are measured in seconds

greater interest after intervention as compare to before intervention which is a clue for us that he / she will not be performing well in intervention. X-axis is representing number of experiments while Y-axis is representing time (average eye contact duration) in seconds. Figure 3.10 is showing the subject participating in Joint Attention (JA) intervention.

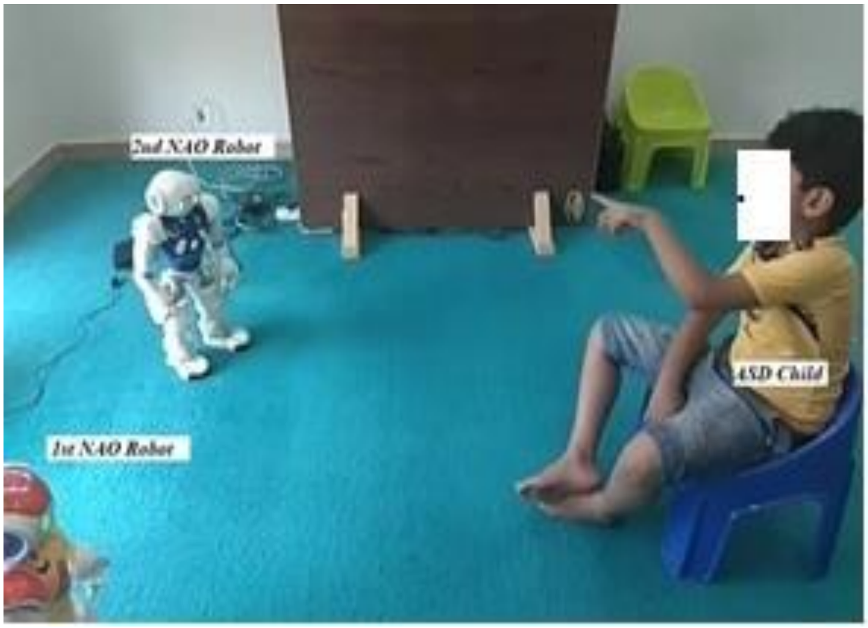

Figure 3.10: Subject participating in joint attention intervention

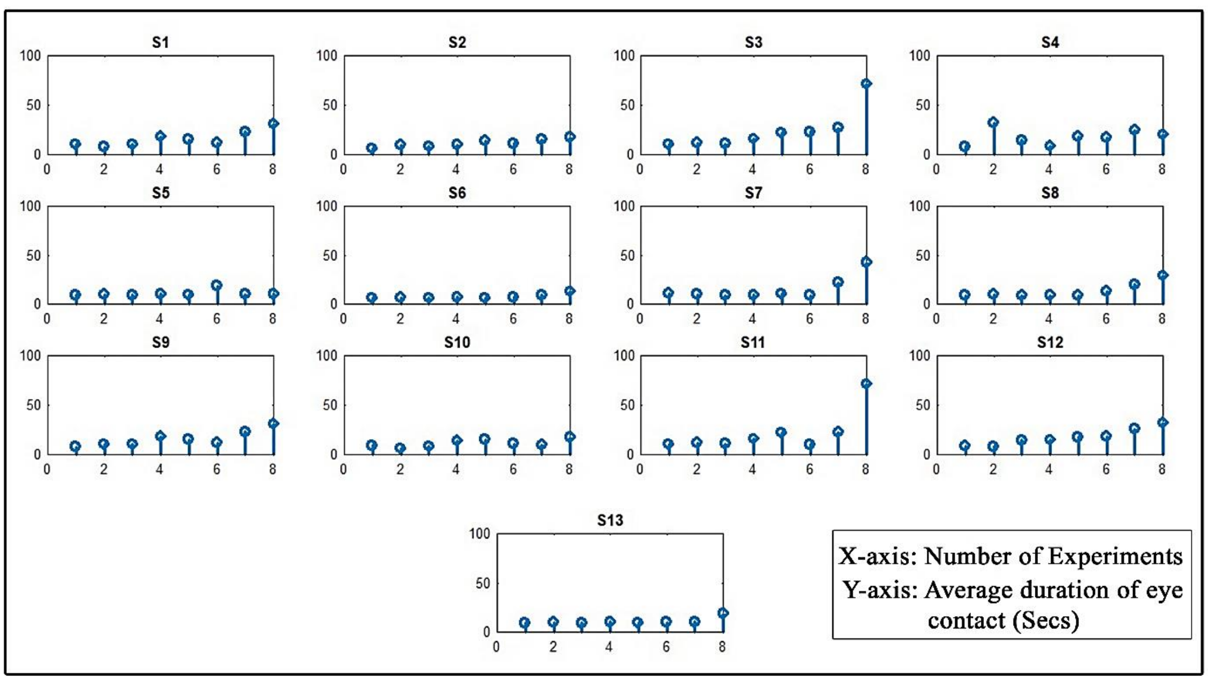

Figure 3.11: average eye contact duration of each subject versus experiments

3.3 Imitation system actuated by joint attention of ASD Child (Part B)

As previously stated, joint attention is most important social skill in human being. This helps a lot in keeping an individual fully attentive and aware of his / her surrounding environment. Figure 3.12 is showing the success rate with respect to both robots of all subjects averaged over all experiments. Robot one was performing two actions. They were:

$$R1_{Actions} = [\,Raise\ hands, Hands\ down]$$

In similar way, robot two was also having two different actions for imitation. They were:

$$R2_{Actions} = [Move\ forward, Move\ backward]$$

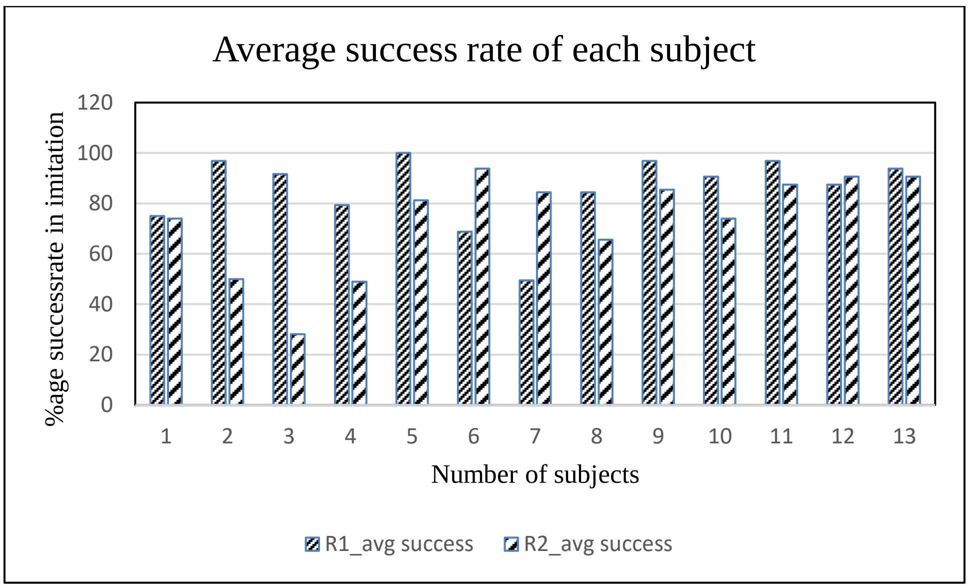

Figure 3.12: Subjects average success rates in imitation over all experiments

Figure 3.13 is providing the number of eye contacts of each subject with respect to robot one and robot two which have been averaged over all imitation experiments. The average number of eye contacts made with both robots is also telling us about the distribution of gaze and attention of ASD subject between these two robots. If the difference between the average number of eye contacts established with robot one and robot two is small, then we can say that the attention was equally distributed between robots. If this is not so, then one robot will be dominating as compare to other one depending upon different factors which are related to subject's own interest and point of view. In figure 3.14, a subject has been shown who was participating in imitation intervention and performing the actions exactly in the same way as the robot is doing.

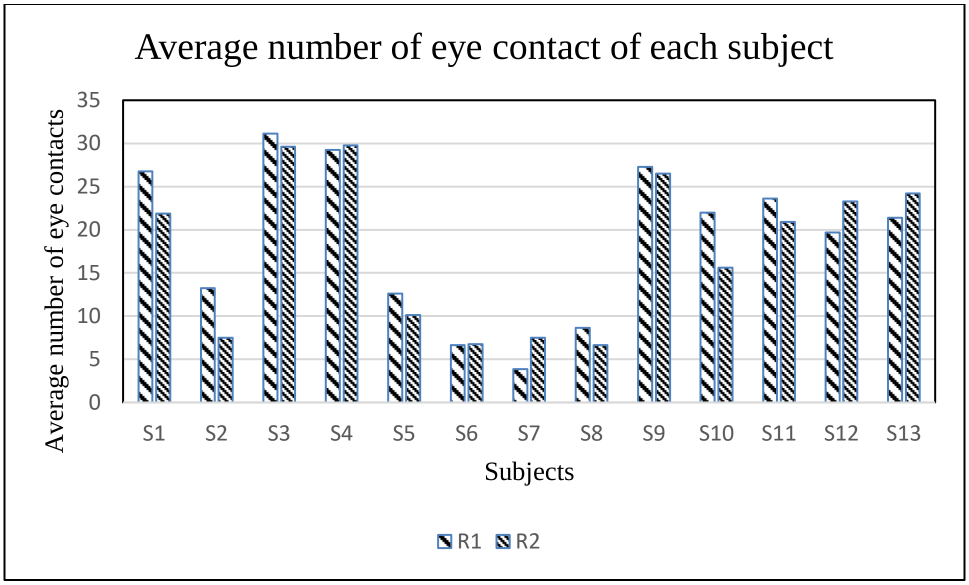

Figure 3.13: average number of eye contacts of each subject over all experiments

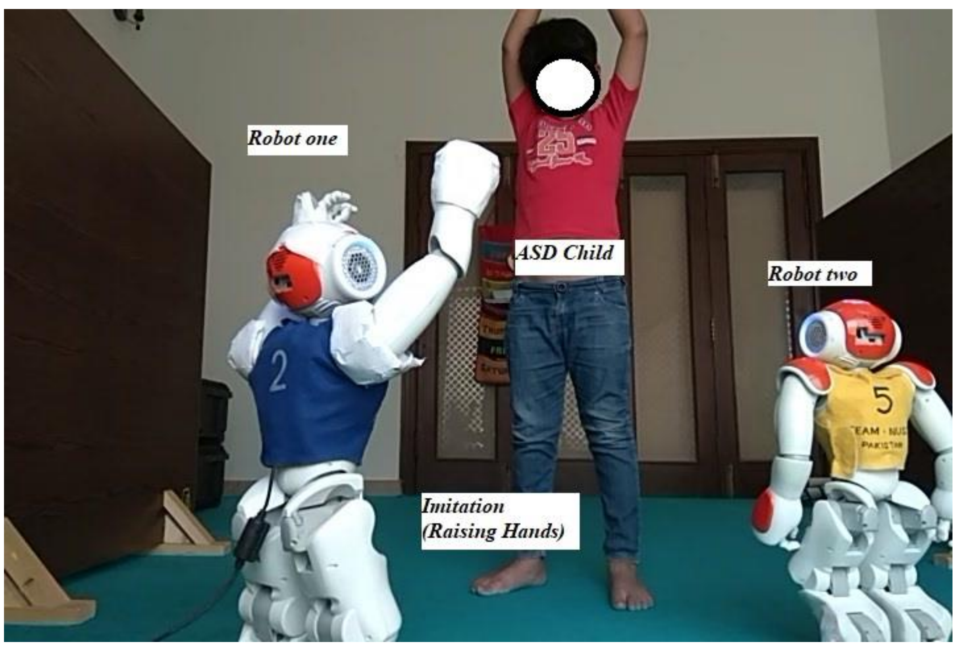

Figure 3.14: Subject participating in imitation intervention

Figure 3.15 is also important and giving more useful information to us. Here four bars are plotted for each subject. These bars are representing that how many times robot one has been actuated by subject and how many times actions of robot one has been followed. In a similar way, how many times robot two has been actuated by subject and how many times actions of robot two has been followed. You can find the difference between the number of actuations done and actual number of followed imitations. It is not necessary that a robot has been actuated by subject and it will be followed by subject as well.

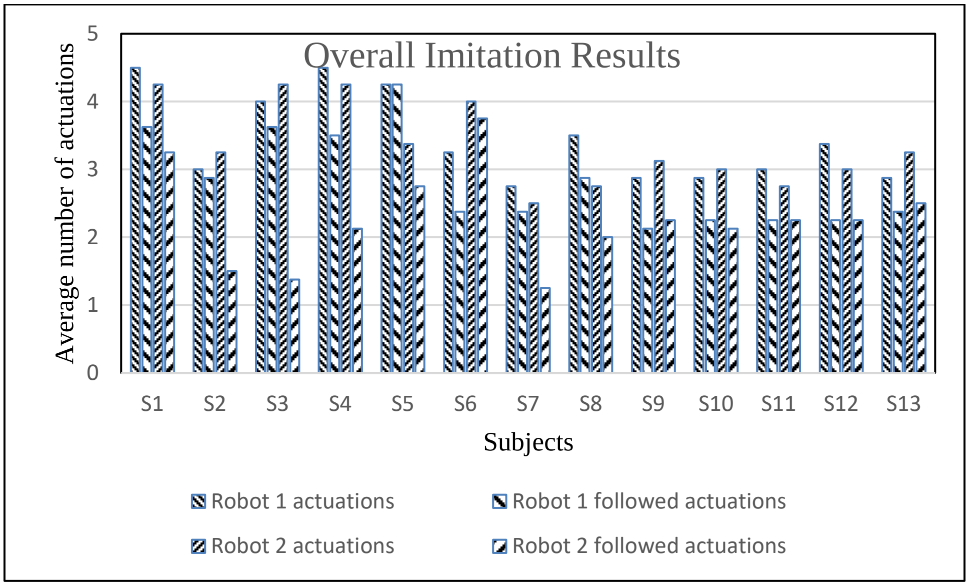

Figure 3.15: over all Imitation intervention results of both robots

Figure 3.16 is showing the overall imitation results. They have been plotted for each subject along with all number of experiments. Most of the time, the number of imitations were constants, means you will find a horizontal line along X-axis for all subjects except subject 9 & 13. The horizontal line is showing the stability of imitation over all experiments of a subject.

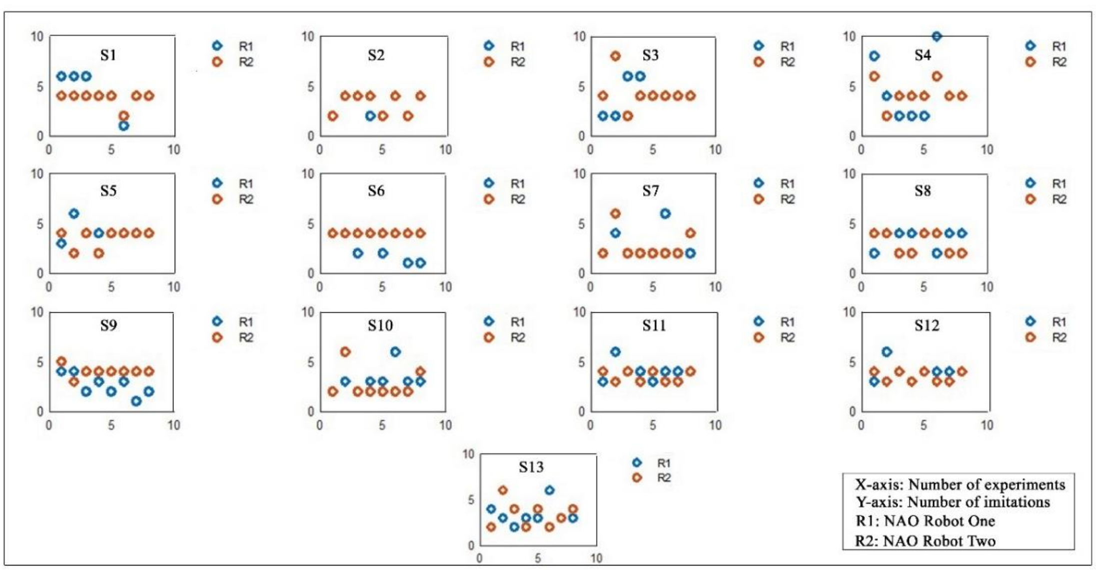

Figure 3.16: Number of imitations versus experiments of each subject

3.4 Cognitive state of brain of ASD Child in both interventions

3.4.1 Intervention 1 (Joint Attention measurement and improvement system)

We have explained that we will be accessing the cognitive state of brain of ASD children before and after intervention. The aim of this assessment is to get an idea about the state of brain of an ASD subject. In our case, we will prefer attentive brain state before the intervention so that subject can perform well in intervention as well. Gathered data is reveling that those subjects, who were not attentive before the intervention, they were not performing well in intervention session. Why a subject was not interested? There are different reasons. It might possible that he / she has lost his / her curiosity completely and many others as well.

Table 3-3 Before intervention

Subject	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Avg Success
S1	*	*	0	*	*	*	*	*	0
S2	*	1	0	1	1	1	*	*	80
S3	*	*	*	1	0	1	1	*	75
S4	*	*	*	*	*	1	0	*	50
S5	*	*	*	*	*	1	1	*	100
S6	*	*	1		1	1	*	*	100
S7	*	0	1	0	0	0	1	*	33.333
S8	1	1	*	*	*	*	*	*	100
S9	1	*	*	*	1	*	*	*	100
S10	*	1	0	1	0	1	*	*	60
S11	*	*	1	1	*	*	*	*	100
S12	*	*	*	1	0	1	*	*	66.666
S13	*	*	*	*	0	1	*	1	66.666

Table 3-4 After intervention

Subject	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Avg Success
S1	*	*	1	*	*	*	*	*	100
S2	*	0	1	1	1	1	*	*	80
S3	*	*	*	1	1	0	1	*	75
S4	*	*	*	*	*	1	1	*	100
S5	*	*	*	*	*	1	1	*	100
S6	*	*	1	*	0	1	*	*	66.666
S7	*	1	1	0	1	0	1	*	66.666
S8	1	1	*	*	*	*	*	*	100
S9	0	*	*	1	*	*	*	*	50
S10	*	0	0	1	1	1	*	*	60
S11	*	*	0	1	*	*	*	*	50
S12	*	*	*	1	1	0	*	*	66.666
S13	*	*	*	*	1	1	*	1	100

Child did not feel comfortable for EEG: *

Fully attentive: 1

Not attentive: 0

Before:	After:
Average P value=0.0144	Average P value=0.0146
Average T value=2.3791	Average T value=2.4298

Table 3-3 and 3-4 are showing the results of assessment of cognitive state of brain of these subjects before and after intervention. The reliability of data can be accessed via calculating its P value and T-value. The standard, which has been set for P & T values is: P value should be equal to or less than 0.05 while T value should be equal to or garter than 1.65. All these conditions are being satisfied in our case which is depicting the reliability of our data and hence the results obtained.

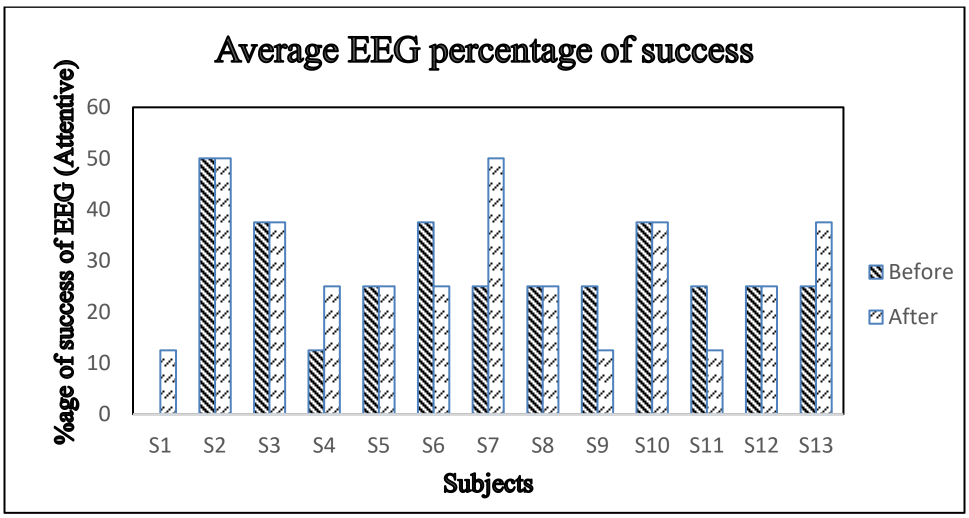

Figure 3.17: EEG percentage of all subjects, before and after intervention, over all experiments

Numerically mentioned data in table 3-3 and 3-4 are represented in the form of bar graphs in figure 3.17. If the fluctuations between before and after cognitive state of ASD child are higher than it means that child has larger impact of intervention and vice versa. For example, if we talk about subject "S7", he / she was interested more after intervention as compare to before intervention, means intervention was having impact on him / her. In a similar way, if we talk about "S5", then he / she was equally attentive before and after intervention, means intervention was not having major impact on him / her.

3.4.2 Intervention 2 (Imitation system actuated by joint attention of ASD child)

Like intervention one, we are accessing the cognitive state of brain of ASD children before and after in intervention two as well. The aim of this assessment is to get an idea about the state of brain of an ASD subject. In our case, we prefer attentive brain state before the intervention so that subject can perform well in intervention. Gathered data is reveling that those subjects, who were not attentive before the intervention, they were not performing well in intervention session. Why a subject was not interested? There were different reasons. It might possible that he / she has lost his / her curiosity completely and many others as well.

Table 3-5 Before Intervention

Subject	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Avg Success
S1	*	1	*	*	*	*	*	*	100
S2	*	1	1	1	0	*	*	*	75
S3	*	*	1	1	1	*	*	*	100
S4	*	*	*	*	1	1	*	*	100
S5	*	1	1	*	1	1	*	*	100
S6	*	1	1	1	1	1	*	*	100
S7	*	1	1	1	*	*	*	*	100
S8	1	1	1	1	*	*	*	*	100
S9	*	*	0	1	*	*	*	*	50
S10	*	*	1	*	*	1	*	*	100
S11	*	1	*	*	0	1	*	*	66.6666
S12	*	*	1	*	1	0	*	*	66.6666
S13	*	*	1	1	1	*	1	*	100

Table 3-6 After intervention

Subject	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Avg Success
S1	*	0	*	*	*	*	*	*	0
S2	*	1	0	1	1	*	*	*	75
S3	*	*	1	1	0	*	*	*	66.6666
S4	*	*	*	*	1	0	*	*	50
S5	*	1	1	*	1	0	*	*	75
S6	*	1	1	1	1	1	*	*	100
S7	*	0	1	1	*	*	*	*	66.6666
S8	1	1	1	0	*	*	*	*	75
S9	*	*	1	1	*	*	*	*	100
S10	*	*	1	*	*	0	*	*	50
S11	1	*	*	*	1	1	*	*	100
S12	*	*	1	*	1	1	*	*	100
S13	*	*	1	0	1	*	1	*	75

Child did not feel comfortable for EEG: *

Fully attentive: 1

Not attentive: 0

Before:	After
Average P value=0.0171	Average P value=0.0207
Average T value=1.9006	Average T value=2.4301

Table 3-5 and 3-6 are showing the results of assessment of cognitive state of brain of these subjects before and after intervention. The reliability of data can be accessed via calculating its P value and T-value. The standard, which has been set for P & T values is: P value should be equal to or less than 0.05 while T value should be equal to or garter than 1.56. All these conditions are being satisfied in our case which is depicting the reliability of our data and hence the results gathered.

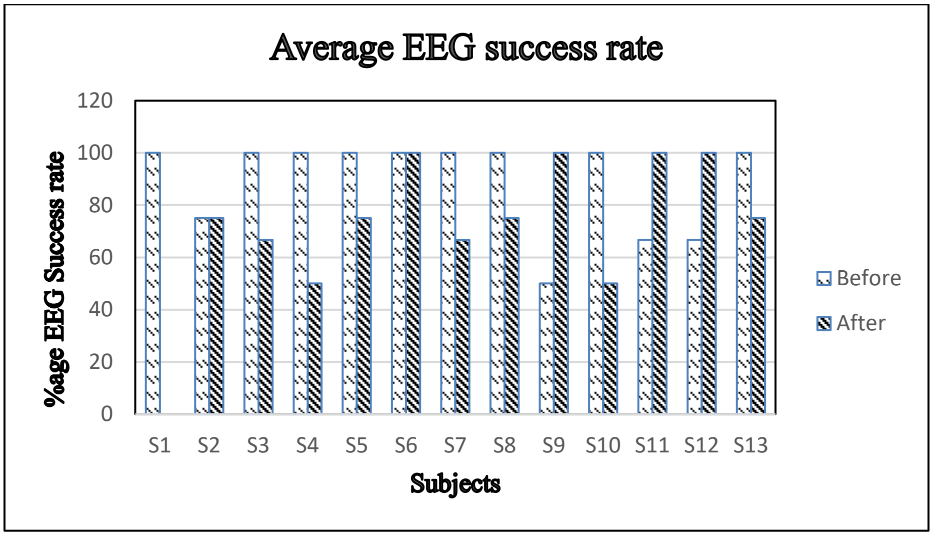

Figure 3.18: EEG success percentage of all subjects, before and after intervention, over all experiments

Numerically mentioned data in table 3-5 and 3-6 are represented in the form of bar graphs in figure 3.18. If the fluctuations between before and after cognitive state of ASD child are higher than it means that child has larger impact of intervention and vice versa. For example, if we talk about subject "S9", he / she was interested more after intervention as compare to before intervention, means intervention was having impact on him / her. In a similar way, if we talk about "S2", then he / she was equally attentive before and after intervention, means intervention was not having major impact on him / her.

CHAPTER 04

TECHNICAL FAULTS AND THEIR SOLUTIONS

There were several difficulties / faults which had been faced while doing these robotic interventions. Three type of faults are: NAO's related faults, Networking related faults, and EEG neuroheadset related faults. These faults are mentioned in figure 4.1. They were 44 in number. Among these 44 difficulties / faults, 30 were related to NAO robots, 09 were related to networking issues and 05 were related to EEG neuroheadset. All these faults are mentioned along with their solutions as well.

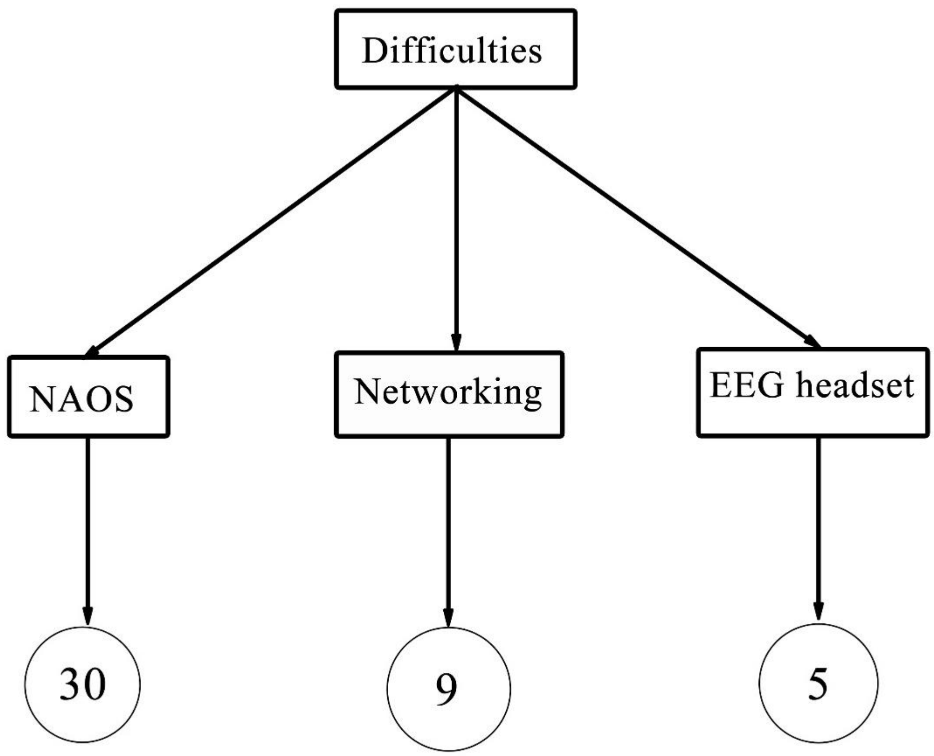

Figure 4.1: Number of technical faults their types

4.1 NAO Humanoid Robot related issues

1. Login id errors

   Solution:

- If you are facing errors in being logged in, then do check your login id, being inserted from terminal, its "ssh nao@xy.xy.xy.x". User name is "nao" only. Where xy.xy.xy.x is IP address.

2. Login IP / Port errors

   Solution:

   - If you are facing errors in being logged in even using the correct user name, then do check the IP address of the NAO robot. Use any IP checking method available and confirm that IP address also belongs to same class being used by LAN.

3. Failing in loading all core module on power up

   Solution:

   - On power up, Naoqi OS starts loading different core modules which are necessary to give life to robot and access to user as well. If anyone among these is failed to load, then you will not be able to use those facilities being offered by the module which failed in loading. Restarting the Naoqi OS should resolve the issue.
   - Sometimes, due to different development processes, it is necessary to shut down the Naoqi OS permanently, un till specified. In that case, you have to login in to robot and run the custom / default naoi script which will wake up Naoqi OS and load all core modules.
   - If still, all core modules are not being loaded, then check the on-loading preference configuration file. This file specifies that which modules should be loaded on power up. Remove all "#" symbols under [core] section. Save the file and restart the Naoqi OS.

4. "I can't connect to cloud services; my system date is wrong"

   If now is say this phrase, then it means that there is no network SSID to whom he should connect. NAO is searching for the network to establish a connection, but unable to find.

   Solution:

- Check that whether network router is active or not? If active, then check the network configuration files that either NAO is searching for correct network or not?
- If NAO is not wirelessly connected, then check that WLAN (RJ45 cable) is properly inserted or not? If inserted, then counter check the IP addresses, they should belong from same class otherwise connection will not be established.

5. Abrupt system halt

   Solution:

   - If you are facing abrupt halting of system, then do check that is your naoqi OS is trying to load any user defined module and it's not being registered due to some run time errors? If so, then remove loading of that module on restarting naoqi OS. This will resolve your issue.
   - If your module is correctly being loaded upon restarting of naoqi OS, then closely look into your code that whether you are trying to access any variable before assigning a value to it? If it's so, then apply proper checks to avoid this situation.

6. Segmentation fault error

   Solution:

   - These faults occur in Linux based systems where a segment of code tries to access a memory location which is not being existed or whose access permission is denied. Rerunning the code will fix this issue. This fault is linked with postulate three. If all core modules are not loaded on power up, and later, in some tasks, we need to access a location associated with that module, failed in loading, we will get segmentation faults.

7. Core dumped error

   Solution:

   - This kind of error only occurs when a piece of code tries to access that memory location which does not exist. If any piece of code is trying to perform any read / write operation on such memory location which is not existing, then again result will be this error. When this error occurs, you will see multiple address of different memory locations on your terminal via logs. Restarting the naoqi OS will resolve this issue. Sometimes, this error also occurs when a lot of modules are running on robot and memory becomes insufficient to handle all of them.

- Try to reduce intra dependencies of your code.

8. Motors getting hot

   Solution:

   - Naoqi OS is equipped with this functionality that it will inform the user via terminal logs about the temperature of the different motors being used in any task, if activated. If this situation occurs with any of the motor, please immediately suspend the Naoqi OS, and let the robot to cool down.
   - Best way in this situation is to power off the robot for ten to fifteen minutes.
   - Beware, do not suspend the naoqi OS while robot is in standing position, if you do, this will remove the stiffness of motors and robot will fall.

9. Battery level is good, but system shows empty

   Solution:

   - This kind of error occurs only when robot's battery is faulty. System will show you the enough level of battery, ranging from 80 % to 99% but robot will shut down via saying that he has insufficient power. You will see this contradiction between Naoqi OS report and whatever being said by robot. If so, then replace the battery of robot.

10. Loading module XYZ failed

    Solution:

    - This error may occur, irrespective of the way of loading code either remote or locally, if you are trying to load a module whose core module has not been loaded successfully. Associated core module's loading is necessary which gives the access to different functionality. See postulate three for curing technique.

- Another possible cause of error is wrong path insertion in configuration file. Robot searches for file in memory, if he fails to find, then you will get this error. Do check the path of the file as well.

11. Resource allocation conflict

    Solution:

    - Due to running of different user / core modules in parallel fashion, it is possible that different segments of different modules are trying to access the same hardware resources. In this case you will get resource allocation conflict. This will cause malfunctioning and your task will completely failed. The possible solution of this thing is to verify that do two segments of different codes are accessing the same hardware resource at same time.
    - Another solution to this problem is, use multithreading with preferences activated. All your designed modules should be thread safe. If so, then there will be no resource conflict error.

12. Connection error in real time emulations

    Solution:

    - If you are doing some emulations using choregraph software and your connection is not being maintained, then pay special attention to IP and Port check boxes. They should be unchecked.
    - If you are doing some emulations using naoqi C++ SDK then do check the IP assigned either dynamically or statically. Moreover, also confirms the port number as well at which naoqi listens.

13. Naoqi OS shutting down while running code

    Solution:

    - This fault only occurs when your designed module is comprising a variable or variables which are being accesses with initialization. Please pay special attention to such variables, if your robot is in standing position, then he will fall.

14. Failed to unregister modules in suspending Naoqi OS

    Solution:

- On restarting naoqi, you have to suspend its operation first. For this purpose, you have use ctrl + c tabs. It might possible that upon first suspension, robot will not respond and if you try to do it multiple time, robot will immediately suspend the naoqi OS and other core modules will not be unregisters properly. Just use one time suspending, if, after some time, robot did not give halt notification then do it again.
- Do not perform this action multiple times adjacently because it will destroy naoqi OS and if so, then factory reset is required.

15. No such module, file or directory error

    Solution:

    - In case of module loading, if core module is not loaded properly, you will get this error. See postulate three for solution.
    - In case of file, read or write operations, do check the existence of file in given directory using “ls” command. It will show you all the available files in a directory.
    - In cased of directory, you can check the existence of directory either via “ls” command or via “tree” command.

16. Local loading error (user defined module)

    Solution:

    - Cross check the path of the local module given in “naoqi/preferences” file under [user] tag. If this path is incorrect, you will be getting an error.
    - If local module is accessing any outside resource, then you will not be able to do this. For example, if your local module is accessing your computer’s directory for writing data, then it will not be possible. The best alternate to this is remote loading.

17. Remote loading error (user defined module)

    Solution:

    - Cross check the path which is being used in remote module. If the path is incorrect, you will be getting core dumped error as well and your module execution will be stopped.

- Do not load your module in nao if it is remote, this will not work in any case.

18. Extending naoqi standard API errors

    Solution:

    - Naoqi OS allows the user to extend their standard API but this is only possible for local modules. If you are trying to do this for remote module, then it will not be possible. Please check that you are extending local modules not remote modules. These modules will act as plugins.

19. Head tactile sensors not working

    Solution:

    - Check for event registration of head tactile sensor because this will allow the event to write data in to memory.
    - Check for the code's nature. This code should belong to event-based programming.
    - Check the sensor's value key. Sometimes putting wrong key stops the data writing into memory and ultimately the whole process as well.

20. Gait parameters are not working

    Solution:

    - Walk of the NAO robot is controllable. You only need to check different attributes which are being used in walk and they are settable as well. Walk configurations have ALValue data types. It will be like structure and vectors. Each attribute along with its value will be a vector in ALValue. Please pay special attention that each entry is not an element in ALValue but ALValue is a set of different vectors containing different attributes along with their values.

21. Strange behaviors (jerking, sitting and standing)

    Solution:

    - If NAO robot is in on state for more than 40 minutes, then this trouble occurs. Instead of having correct module and other things, your robot will behave strangely. Immediately shut down the robot and let him to rest for half an hour at least.

22. DCM errors

    Solution:

    - DCM is an abbreviation of Device Communication Manager. If you are getting these faults, then you must have to fix them. Faults in this section means that there is no synchronization between different hardware resources of robot. One such fault is, robot is moving, and his legs are not synchronized in different actions. Robot is lagging in performing actions. If the error is due to software, then factory reset is the solution else it will become hardware-based issue which cannot be repaired by an individual.

23. Listening port error

    Solution:

    - Naoqi OS listens at specific port number under specific Ip number. The default port number is 9559. Please check that port number has not been changed by anyone under connection tab in choregraph.
    - If you are running code remotely, then cross check the port to whom you are connecting to. If you are connecting to wrong port, you will get error regarding connection establishment.

24. File writing error (in NAO)

    Solution:

    - If you are writing a file via local module, then you must have to specify the path of the file along with name & extension. Only name and extension will not work in NAO robot.
    - If you are writing a file via remote module, then same thing will be true. Remote module is preferred on local module because it gives access to both, computer's directories and NAO hardware and directories.

25. Previous module initialization upon loading new one

    Solution:

    - If your code contains any loopy section and you have not introduce any other external interrupt to terminate it, then this error will occur. Please note that this error is evident only in case of loopy remote modules. The best way is to design a local module, containing some external interrupt to control / terminate the loopy segment in code, and then load it into robot. This will eliminate above error.

26. Invalid key errors

    Solution:

    - Naoqi OS provides different keys which are used to access different hardware parts and different data locations / variables in memory under different registered events. If someone is putting wrong key, in either accessing memory's location or a hardware resource, then system will not respond. Please accurately place all the keys.

27. No data in memory

    Solution:

    - If you are accessing different variables associated with events and you are not getting any data, then cross check the registration of events and keys being used. If anyone between these two is in correct, then system will become unresponsive.

28. Wireless access is blocked

    Solution:

    - If you are accessing NAO robot wirelessly and you are unable to logged in, then restart your robot because it might possible that wireless communication configuration file had not loaded properly.
    - Check for the router and connection of your computer as well, that are you really connected to correct network.
    - Check your IP address and robot's IP address (to whom you know previously) and then see that whether they belong to same class or not? They should belong to same class.
    - Check the network communication files in NAO and check the "WLAN" property / header. You should specify the settings and then restart the robot.

29. IP binding failed

    Solution:

- If you are connecting NAO to a wireless / wired network and assigned a static IP address and if that IP address is not in the same class as the router is in, then you will get IP binding failed errors. So, you may let the robot to get IP dynamically, which will obviously belong to same class as the router is in or you can correct the static IP address.

30. Event does not work

    Solution:

    - You must register to an event before utilizing it. Cross check the event name.

4.2 Networking related issues

1. Computer failed to connect to a network

   Solution:

   - A computer may fail in connecting to a network. Please check the security type of network and the IP address of computer as well. If IP address is static, then cross check the class of IP which should match with network's IP address class.

2. NAO failed to communicate with computer

   Solution:

   - NAO can work as a server or as a client, ad correspondingly computer can work as a client and server. If in these cases, NAO is unable to communication with computer, then cross check the IP address of NAO, computer and Router. Moreover, verify that both, NAO and computer, are connected to same network.

3. NAO failed working as server

   Solution:

   - If NOA is not properly working as a server than cross check the IP address and its binding as well. If you use wrong IP address, the binding will be failed and hence there will be no communication.

- Check the client's target IP address to whom it's trying to connect to. It should match with the server's IP address.
- Verify the port number as well. Moreover, port number, being utilized by server, should not match with the default one, i.e., 9559. Port number should be something else like 9000, or 8000 etc.

4. Port conflict in server running on NAO

   Solution:

   - Naoqi OS listens on a port 9559 and server running on NAO should not use that because it will be occupied by naoqi. Same IP address are allowed but same port number is not allowed.

5. NAO failed working as client

   Solution:

   - If NAO is failing working as a client, then cross check the target IP address and port number of client running on NAO. They should match with server's IP address and port as well.
   - Cross check that whether the server is running or not? If server fails in running, client will not work.

6. Port conflict in client running on NAO

   Solution:

   - For client, you do not need to define its port. Client choses its port dynamically. If luckily two clients have same dynamic port numbers, then this error will occur and data of two clients will be mixed. The only solution to this problem is to increase the gap between different server's ports and then run them one by one.

7. Multiple network gateway error

   Solution:

   - One gateway is assigned to only one network. Multiple gateways cannot be assigned to same network.

8. IP address' class error

   Solution:

   - All the devices connected to a network and all the servers and clients running on different devices should have different IP addresses which should belong to same class. If this is not so, then we will be having IP address class errors.

9. Multiclient communication with single server failed

   Solution:

   - Multi-clients can communicate with a single server. At the movement of acceptance of connection, different integer identifiers will be allocated to them. You can access these clients via using these integers identifies. You must have to ensure that all the clients are connecting to correct IP address of server and port number as well.

10. IP conflicts

    Solution:

    - In a network, having different devices connected, if any of two devices have same IP address then you will get IP conflicts. In case of dynamic IP assigning, this possibility is approximately vanished but in case of static IP assigning, this danger is higher so, beware of this thing.

4.3 Emotive EPOC neuroheadset related issues

1. EEG headset has stopped recording of data

   Solution:

   - Save the file and then off and on the neuroheadset. This will resolve the issue.

2. None of the signal is being recorded

   Solution:

- Please check that either neuroheadset is connected to your laptop or not? Please note that changing of hardware will not immediately connected the computer. You must have to use user id to connect to neuroheadset.

3. Signal strength of an electrode is weak

   Solution:

   - Check that whether the electrode is connected to its location properly? Is yes then did you apply saline solution before using it? Apply saline solution and properly place the electrodes.

4. Reference nodes are not connected, is my data valid?

   Solution:

   - All the signals being extracted from neuroheadset are recording via considering two references, located at the back of each ear. If reference nodes are not properly connected, then recorded signals will be inaccurate.

5. C++ SDK VS Emotive EPOC Application

   Finding:

   - C++ SDK and Emotive EPOC application, both give you access to live EEG signals recording. In C++ SDK, you can record signals, but you will not be able to see in real time that which node is connected, and which is not? While in Emotive EPOC application, you have this facility.

CHAPTER 05

CONCLUSION AND FUTURE WORK

5.1 Conclusion

Joint attention and imitation are two important social skills in ASD children. Since autism spectrum disorder is a neurodevelopment disorder, it affects different social skills of an ASD person. Joint attention is too much important in properly and correctly responding to different stimulus coming from surrounding environment.

In this research work, we have designed two novel therapeutic interventions for ASD children. These interventions have been designed using NAO humanoid robots which is closer to the human physical appearance. Designed therapies are:

i. Multi-humanoid robot based joint attention measurement and improvement system with and without reinforcement stimuli for ASD children.

ii. Multi-humanoid robot based imitation system actuated by joint attention of ASD children.

In first intervention, we are quantitively measuring the joint attention of ASD children. We introduce joint attention improvement system as well which utilizes reinforcement stimuli. There are six different kinds of reinforcement stimuli. They are: Blink, Rasta, Hi, Hello, Standing and waving arm, and sitting reinforcement stimuli. These reinforcement stimuli were having different impacts on ASD child. We started from least effective reinforcement stimulus to most effective one and gradually increasing the effectiveness. This gives us success in measuring joint attention first and then improving it in ASD child. Joint attention is important because it makes one enable to properly and accurately respond towards different events being occurred in surrounding environment. These reinforcement stimuli were included to capture attention of subject if he / she is not paying attention towards NAO robots. Designed multi-humanoid robot based joint attention system is new one which really works in our interventions.

In second intervention, we have designed multi-humanoid robot based imitation system actuated by joint attention of ASD subject. We designed first therapy for joint attention improvement and then another one for improving imitation skills based on previous one, i.e., joint attention. Here only four actions were defined between two NAO robots. First robot was either moving forward or backward while other one was also having two actions: raising your hands and hands down. Child's imitation was recorded using Kinect V4.

In both interventions, before and after, we were accessing the cognitive state of brain of ASD children as well. The aim of accessing the cognitive state of brain is to see the effect of interventions on ASD child. we categorized ASD child based on EEG data into two categories. They are: attentive and non-attentive. This categorization is done using alpha band analysis of EEG. We utilized PSD peak analysis techniques to access the cognitive state of brain of ASD child.

5.2 Future Work

Following upgradations are possible in our designed interventions.

I. These interventions; joint attention and imitation, can be tested on down syndrome children and we can give the comparison of DS and ASD children, as we dealt with ASD subject only.
II. We can make joint attention system adaptive with respect to joint attention of ASD child.
III. We can make joint attention system adaptive with respect to cognitive state of brain of ASD child.

5.3 Acknowledgement

We acknowledge all the contributions and collaborations from Autism Resource Center Islamabad (ARCI), Pakistan. This research was conducted because of mutual collaboration between RISE Lab, dept of robotics and intelligent machine Engineering (RIME), SMME, National University of Sciences and Technology (NUST) Islamabad, Pakistan and Autism Resource Center Islamabad (ARCI). We tank all the members who were involved in this project either directly or indirectly.

APPENDIX A

Subject's Details

Table A-1 Details of all subjects participated in interventions

Sr.	Age (Year)	Sex	Autism case	Problems	Consent form	Childhood Autism Rating Scale Score (CARS)	Remarks
1	8-9	M	Severe	Auditory sensitive	Yes	40	-
2	15	M	Mild	-	Yes	32	-
3	9	M	Moderate	Auditory	Yes	36	-
4	9	M	Minimal	-	No	27.5	Along with personality issues
5	6	M	Moderate	Poor body coordination and limitations with motor movements	Yes	33.5	-
6	8-9	M	Moderate	-	No	35	With hyperactivity
7	9	M	Minimal	-	Yes	22.5	With behavioral issues
8	8-9	M	Moderate	-	Yes	34.5	With IQ issues
9	8-9	M	Mild	-	Yes	33.5	With behavioral issues
10	4	F	Minimal	-	Yes	22.5	With hyperactivity
11	5-6	M	Moderate	Moving objects approaching towards child disturbs him	Yes	35.5	With hyperactivity
12	3	M	Minimal	-	Yes	20.5	-
13	8-9	M	Mild	-	No	30.5	-

APPENDIX B

Project Gant chart

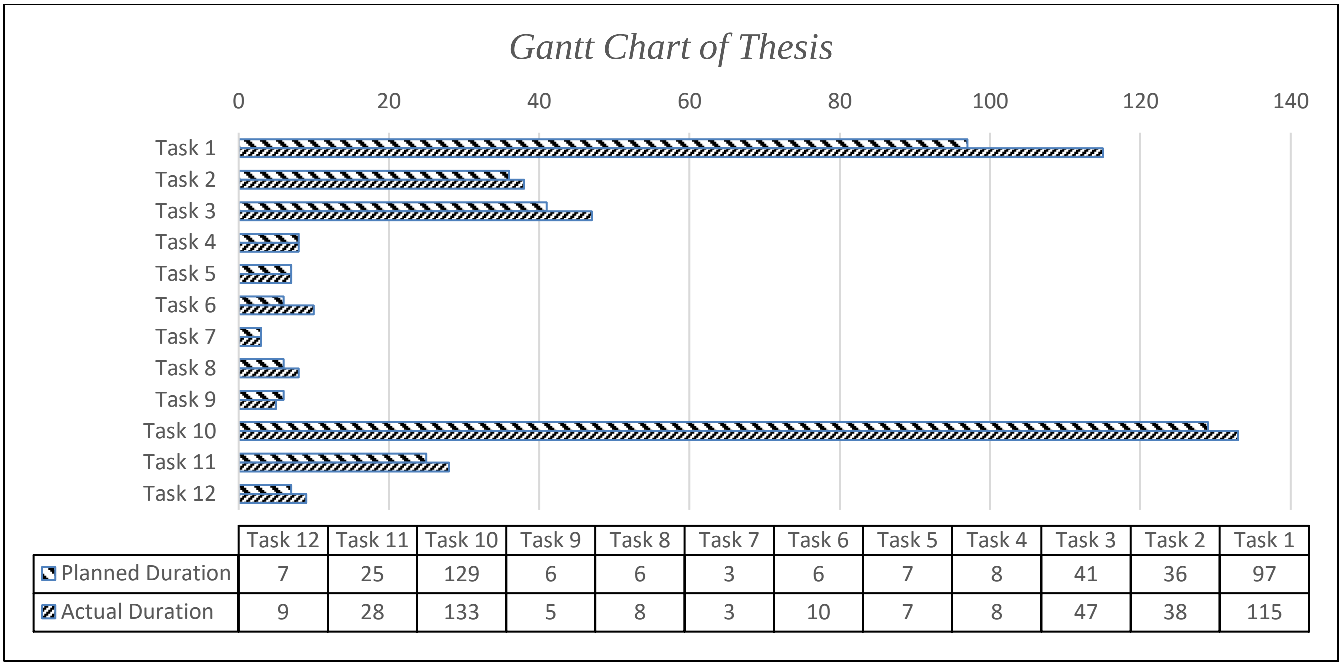

Figure B.1: Gantt Chart of project

Tasks	Activity	To be completed by (Date)
1	HRI & autism related literature review	November 13, 2017
2	Problem formulation and research topic finalization	December 20, 2017
3	NAOqi OS basics and essential programming work of NAO robot	January 31, 2018
4	Documents preparation for initiating Proposed therapies	February 7, 2018
5	Networking, socket programing for wireless communication	February 15, 2018
6	First therapy implementation	February 22, 2018
7	In house debugging / testing of first therapy	February 26, 2018
8	Second therapy implementation	March 05, 2018
9	In house debugging / testing of first therapy	March 12, 2018
10	Starting autism sessions, gathering and compilation of statistical data	March 14, 2018
11	Papers writing and publishing process	July 30, 2018
12	MS Thesis defense	August 30, 2018

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