ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

ASSISTANT HUMANOID ROBOTS FOR SIGN LANGUAGE TUTORING

M.Sc. THESIS

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Department of Computer Engineering

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JANUARY 2014

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<u>İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ</u>

İNSANSI ROBOT DESTEKLİ İŞARET DİLİ ÖĞRETİMİ

YÜKSEK LİSANS TEZİ

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Neziha Akalın, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID 504101547, successfully defended the **thesis** entitled **"ASSISTANT HUMANOID ROBOTS FOR SIGN LANGUAGE TUTORING "** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

FOREWORD

Since February 2013, I have been conducting research on assistive robotics. I have experienced this period very interesting and instructive. At the beginning, I had little knowledge about robots but the support of my supervisor Asst. Prof. Hatice Köse made me incredible progress in a short time. I would like to give my special thanks to my supervisor, Asst. Prof. Hatice Köse for her great help during this journey. Her valuable insights directions gave me needful guidance to complete this thesis.
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December 2013

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ABBREVIATIONS

HRI	**:** Human-Robot Interaction
SL	**:** Sign Language
DOF	**:** Degree of Freedom
TSL	**:** Turkish Sign Language
ASD	**:** Autism Spectrum Disorder
HMM	**:** Hidden Markov Model
ASL	**:** American Sign Language
GUI	**:** Graphical User Interface
SDK	**:** Software Development Kit

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ASSISTANT HUMANOID ROBOTS FOR SIGN LANGUAGE TUTORING

SUMMARY

As the usage of humanoid robots becomes more common, the applications of assistive robotics and the idea of using robots as therapy tools have increased in recent years. Many applications of human-robot interaction include creating intelligent technologies to help people improving their life quality and social interaction capability. Human is a social being, therefore the social interaction is an important need in human life. People try to find common ground for interaction establishment. The common ground can be found by communication and from this point of view, the importance of communication is conferred. Sign language is the natural communication medium for the people who cannot communicate verbally. Sign Language is a visual language that is composed by a combination of hand gestures, facial expressions, and head movements.

This work is part of an ongoing project that aims to employ humanoid robots as sign language tutoring assistance. The main goal of the study is to use the humanoid robots with imitation based interaction games for helping children with communication problems, especially hearing impaired children and children with Autistic Spectrum Disorder.

The difficulties with 2-D instructional tools developed for sign language tutoring and the lack of sufficient educational material in this field, motivate us to use child-sized humanoid robots as sign language tutoring assistants. The humanoid robots can perform various elementary sign language words to assist teaching these words to hearing-impaired children. In this thesis, a framework is proposed for ideal humanoid robot – children interaction. The system proposed here can be easily adapted to the children's disability degree. Teaching can be achieved using interaction games based on non-verbal communication, turn taking and imitation, designed specifically for the robot and child to engage each other in play.

In this study, two types of humanoid robots are used: Nao H-25 humanoid robot and Robovie R3 humanoid robot. Despite the physical limitations of Nao robot, which are finger dependency and short limbs, more than one hundred words from Turkish Sign Language are implemented. The toy like appearance of Nao robot attracts children to interact with it. The participants interact with Nao in a comfortable mood. There are currently 13 signs implemented on Robovie R3 robot. The user studies showed that the children attending the studies perceive Robovie R3 robot as a peer. The modified Robovie R3 humanoid robot being used in our project, has two five-fingered hands so it is more successful in teaching sign language, than the Nao robot, since sign languages (Turkish Sign Language is tested for this thesis) require independent finger gestures in most of signs.

The overall scenario includes three different modes. In the first mode, the participants and the robot gain familiarity with each other and the participant also introduced with signs. In this mode, the robot tries to keep the participant's interest fresh by detecting the participant's face. If the participant loses his/her interest, the

robot gives motivation to the participant. In the second mode, the participant and the robot repeat signs together. In this mode, the aim is reinforcement of signs. In the third mode, the robot and the participant play an interactive game. There are four different interactive games based on this scenario in the current system. The system can be easily adapted to different words and different games.

The system is tested with different participant groups including kindergarden school children, primary school children, teenagers and adults. The obtained results are quite promising and motivate us for further studies.

İNSANSI ROBOT DESTEKLİ İŞARET DİLİ ÖĞRETİMİ

ÖZET

İnsansı robotların yaygınlaşmaya başlamasıyla birlikte robotların bir tedavi aracı olarak kullanılması fikri de ön plana çıkmıştır. İnsan-robot etkileşimi ile ilgili pek çok uygulama, insanların hayat kalitelerini iyileştirmeye yardımcı olmak ve sosyal etkileşim kapasitelerini geliştirmek için zeki uygulamalar geliştirmeyi amaçlar. İnsan toplumsal bir varlıktır dolayısıyla toplumsal yaşam içindeki insanın sosyal etkileşimde bulunması doğal bir ihtiyaçtır. İnsanların etkileşim kurulabilmesi için ortak bir zeminde/noktada buluşmaları gerekir. Ortak nokta ise ancak iletişimle bulunabilir, buradan hareketle iletişimin önemi ortaya çıkar. İşaret dili sözlü olarak iletişim kuramayan kişiler için doğal bir iletişim aracıdır. İşaret dili görsel bir dildir, el/kol/yüz ve baş hareketlerinin birleşiminden oluşur.

Bu tez çalışmasında insansı robotların işaret dili öğretimini de kullanılması amaçlanmıştır. İnsansı robotlar, taklit tabanlı etkileşim oyunlarıyla iletişim problemi olan kişilere bilhassa işitme engelli ve otistik çocuklara yardımcı olmak için görevlendirilmiştir. İşaret dili eğitimi için üretilen iki boyutlu eğitim araçlarıyla öğrenmenin zorluğu ve bu alanda kullanılacak yeterince eğitsel araç olmaması bizi çocuk boyundaki insansı robotların işaret dili öğretiminde kullanımı doğrultusunda motive etmiştir. İşaret dili öğretiminde eğitmenin fiziksel olarak bulunması öğrenmede büyük pozitif etkiye sahiptir. Bu çalışmada göstermiştir ki insansı robotlar, işaret dili öğretiminde etkili bir araç olarak kullanılabilirler.

Bu tez çalışması kapsamında iki tip insansı robot kullanılmıştır; Nao H-25 ve Robovie R3. İnsansı robot Nao H-25 birbirinden bağımsız hareket edemeyen üç parmağa sahiptir. Nao robotun parmak bağımlılığı ve kol kısalığı gibi fiziksel kısıtlarına rağmen Türk İşaret Dili'nden yüzden fazla işaret robot üzerinde gerçeklenmiştir. Robotun oyuncak-vari görünüşü çocukların onunla etkileşimini kolaylaştırmaktadır. Çalışmada kullanılan Robovie R3 insansı robotu ise standart Robovie R3 robotunun değiştirilmiş halidir. Standart versiyona göre daha fazla serbestlik derecesine sahip olan R3, aynı zamanda birbirinden bağımsız hareket edebilen beş parmağa sahiptir. İşaret dilinde büyük öneme sahip parmak hareketlerini kolayca yapabilmesi, hareketlerin daha anlaşılır olmasını sağlamaktadır.

İşaret dili öğretimi, sözsüz iletişime dayalı etkileşim oyunları, sıralı iletişim ve taklit içeren oyunlar yoluyla başarılabilir. Oyunlar çocuklar ve robotun etkileşimi için özel olarak tasarlanmış olup çocukların robotla etkileşimini ve iletişimini teşvik eder niteliktedir. Kullanıcı tabanlı testler esnasında gözlemlendiği kadarıyla katılımcılar robotla etkileşim esnasında rahat bir ruh haline sahiptirler. Bütün senaryoda üç mod vardır. İlk modda katılımcılar ve robot birbirlerine karşı aşinalık kazanırlar. Katılımcılar işaretlerle tanışır. Bu modda robot katılımcının ilgisini taze tutmaya çalışır. Robot katılımcının yüzünü izler, katılımcının yüzünü kaybettiğinde katılımcıyı kendisini izlemesi için motive eder. İkinci modda katılımcı ve robot birlikte hareketleri tekrar ederler. Bu modda amaçlanan hareketlerin

pekiştirilmesidir. Üçüncü modda robot ve katılımcı karşılıklı bir etkileşim oyunu oynarlar. Önerilen sistemde dört farklı oyun tasarlanmış ve gerçeklenmiştir fakat sistem rahatlıkla daha farklı oyun ve kelimelere kolaylıkla adapte edilebilir.
Duyma engeli olmayan yetişkinler ve çocuklarla yapılan kullanıcı tabanlı testlerle, bir seansta öğrenilebilecek optimum kelime sayısının tespiti yapılmış ve 8-10 kelimenin bir seansta öğretilmesinin ideal olduğu kanısına varılmıştır. Ayrıca testlerde deney kurulumunun en iyi hale getirilerek öğrenmenin artırılması hedeflenmiştir. Kullanıcı testlerinin kurulumu ve kelime sayısı sistematik olarak değiştirilmiş, basitten zora doğru bir yol izlenmiştir. Her test sonrası katılımcıların görüş ve önerileri göz önünde bulundurularak bir sonraki test kurulumu hazırlanmıştır.
Çalışma kapsamında kullanılacak verileri toplamak için birçok farklı kaynak kullanılmıştır. Bu kaynaklar; oyunun son modunda katılımcılara dağıtılan ve oyun süresince izledikleri işaretleri öğrenip öğrenmediklerini kapsayan testleri, oyun düzeneğini geliştirmek amacıyla deneyler esnasında dağıtılan anketleri, daha sonra kullanılmak üzere kayda alınan video kamera görüntülerini ve Kinect kamera kayıtlarını ve katılımcılar ile yapılan sözlü anket sonuçlarını içerir. Bu çalışmada tasarlanan sistem yapısı ve açıklamaları itibari ile işitme engelli çocukların herhangi bir ek yardıma ihtiyaç duymadan işaret dilini öğrenmelerini sağlayacak şekilde tasarlandı. Burada önerilen sistem aynı zamanda normal gelişimi olan çocuklarla da oynanabilir. Önerilen sistemin modları işaretlerin gerçeklemesi, işaretlerin anlamlarının öğretilmesi ve sıra alma üzerine kuruldu. İşitme engelli çocuklar, kendilerine uygun özel olarak tasarlanmış oyunlardan yoksundurlar. Tasarlanan oyunlar, çocukların yeni işaretler öğrenmesine ve öğrendikleri işaretleri robotla etkileşim esnasında kullanmalarına fırsat verir. İlk adım olarak deneyler yetişkinlerle test edildi. Çocuklarla test etmeden önce deney kurulumunu iyileştirmek ve çocuklar için en uygun deney düzeneğini hazırlamak için yetişkinlerle yapılan deney sonuçları çalışmanın ilerlemesinde yol haritası niteliğindedir.
Bu tez kapsamında işaret dili eğitiminin bir parçası olarak kullanılmak üzere sosyal robotik bir çatı (framework) önerilmiştir. Önerilen çatı sistemi tanıma modülü, gerçekleme modülü ve davranış veri tabanı içerir. Aile bireyleri ve eğitmenler tarafından kullanılabilecek sistem, duygu tanıma, görüntü tanıma, hareket tanıma, yüz tanıma ve konuşma tanıma modülleri içerir. Sistemin tamamı gerçeklendiğinde, elektroensefalografi ve göz izleme araçları da eklenerek çocukların duygu durumu saptanarak robotun davranışlarını bu verilere göre şekillendirmesi sağlanacaktır. Gerçeklenmiş sistem, çocuğun ilgi durumunu tespit etmek için yüz izleme sistemi kullanmaktadır. Sistemin yapısı çocuğun robotun karşısında öğretmen, öğrenci ve arkadaş rollerini almasını sağlar. Çocuğun değişik roller alarak sosyal iletişim ve etkileşim yeteneklerinin gelişmesi, kendine güveninin artması hedeflenmiştir.
İşitme engelli çocukların bilişsel gelişimini inceleyen uzmanlara göre işitme engelli bir çocuğun bir ana dilinin olmasının (işaret dili ya da sözlü dil) çocuğun zihinsel gelişimini ciddi manada olumlu etkilediğini belirtiyorlar. Çocuk tamamen işitme engelli ise ve ailesi işitme engelli değilse çocuğun erken yaşlarda işaret dili öğrenmesi gerçekleşemiyor ve çocuk bir ana dil edinmede zorluk yaşamaktadır. Robotların işaret dili öğretmede kullanılmasıyla bu ihtiyacın giderilmesi amaçlanmıştır. Çalışmalarımıza danışmanlık yapan uzmanlar, eğer çocuk kısmen işitebiliyorsa (ya da koklear implant gibi işitme cihazları kullanılıyorsa) melodik bir çocuk sesi ve renkli kartların kullanımının, eğer tamamen işitme kaybı varsa sadece renkli kart kullanımının çocukları motive edeceğini ve konuşma tedavisinde onlara yardımcı olacağını düşünmektedir. Renkli resimlerin olduğu kartların kullanımı,

işitme bozukluğu olan çocuklarla iletişim kurabilmemizi ve de etkileşim oyununu devam ettirebilmemizi sağlamıştır. Oyun sonunda yine renkli resimlerden oluşan testlerle katılımcıların öğrenme performansı sınanmıştır.
Kullanıcı deneylerinin sonuçlarında görülmüştür ki çocuklar her iki robotla da son derece keyifli bir şekilde oynamışlar; fakat R3'ün hareketlerini daha net anladıklarını ifade etmişlerdir Nao ile oynamayı tercih etmelerine rağmen R3 robotuyla daha çok ilgilendikleri ve işaretleri ondan öğrenmeyi tercih ettikleri gözlemlenmiştir. Bu doğrultuda, çocukların Nao'yu bir oyuncak olarak gördükleri, R3'ü ise daha çok bir akranları gibi algıladıkları söylenebilir.
Bu çalışmada insansı bir robotun işaret dili öğretimindeki yararlılığı ve performansı değerlendirilmiştir. Deneyler, çocuklarla test edilmeden önce ilk olarak yetişkinlerle test edilmiştir. Yetişkinlerle yaptığımız testlerde asıl amacımız, işitme bozukluğu olan çocuklarla herhangi bir test yapmadan önce deney düzeneğinin mümkün olduğunca mükemmelleştirilebilmesi için atılması gereken adımların belirlenmesidir. Testlerden elde edilen ilk sonuçlar, insansı robot ve çocuklar arasında daha uygun bir etkileşim kurulabilmesini sağlamak amacıyla yapılması gereken değişikliklerde yol gösterici olmuştur.
Önerilen robotik çatının tamamının gerçeklenmesi ve sistemin beş parmaklı Robovie R3 robotuna taşınması gelecekte yapılması planlanan çalışmalardır. Ayrıca çalışmanın hedef kitlesi olan işitme engelli çocuklarla uzun süreli testler yapılarak çalışmanın uzun soluklu etkileri incelenecektir.

1. INTRODUCTION

The human-robot social interaction have been getting popular among the academic communities in recent years. Human–Robot Interaction (HRI) is a study field trying to evaluate human and robot interaction, to design robotic systems for humans in order to interact with robots more comfortably and to understand their communication behaviors [1]. In the research area of HRI, communication between humans and robots is the key point. There are many applications on verbal communication [2-5] but the number of researches on the realization of sign language (SL) is few because two human-like hands are necessary to implement SL. Recent developments in robot technology drive the research in HRI to investigate machines by means of communication that are naturally used between humans, such as speech and gestures. Hand and face gestures are a complementary part of the speech. The basis of sign languages are formed from the gestures that are consciously and unconsciously used in every aspect of human communication.

Many robotic platforms serve the goal of developing human-robot social interaction [6-12]. Social interaction among humans is a good model for the researchers to develop similar interaction of robots with each other and with humans.

The presented work in this thesis is the part of “Robot Sign Language Tutor” project, which is supported by the Scientific and Technological Research Council of Turkey under the contract TUBITAK KARIYER 111E283 and Istanbul Technical University Scientific Research Projects Foundation under the contract BAP 37255. The project examines the humanoid robot usage in sign language teaching. The experiments conducted within the scope of this thesis tries to investigate the engagement capability of humanoid robot usage for sign language teaching with hearing impaired children.

1.1 Motivation

Hearing impaired or deaf people are partially or completely lacking in the sense of hearing. Deafness or hearing impairment is defined as lack of ability in processing linguistic information by hearing, which affects a child's educational performance [13]. Language acquisition, which is an extremely crucial process for brain development and intelligence, is completed at ages of 2 or 3 years. Existence of sufficient native language materials and their employment during education have great importance for preschool training. Acquiring a language is very difficult for some people who have disabilities. The native language acquisition constitutes a crucial part for the preschool education. Hearing impaired children have chance to learn sign language as their native language before they learn a written language, if their parents are hearing impaired as well. In the hearing-impaired communication, sign languages are like the spoken languages and they develop the communication naturally within hearing-impaired communities. Hearing-impaired communities develop their own sign languages independently from the spoken language of the region and the region culture effects the sign language.

Employing robots in different fields such as industry, service, entertainment, medicine and healthcare increased the importance of robots in human life. Using robots as theurapic tools by creating social relationships between a human and a robot is an innovative approach. It may be very helpful in the development process of children suffering from different degrees of impairment.

One of the important activities for children intellectual development is the game play. Playing a game engages the children to handle various objects, encourage them for being social with the other individuals, in the meantime to adopt an appropriate behavior in order to interact with them [14]. Playing a game contributes the child development by improving their social and cognitive skills that are necessary to communicate with other individuals [15]. Usage of robots as therapeutic tools can be very helpful for children with different levels of disabilities. Playing a game is an important activity in child development. According to the International Classification of Functioning and Disabilities- Version for Children and Youth (ICF-CY) the World Health Organization remarks play to be one of the most important standpoints of a child's life [16]. Several studies show that learning from physical robot is more effective than 2D tools (i.e. TV, or videos) for children because children can touch them and get response from them, chat with them, and see the movement directly [17]. The humanoid robots based interactive learning environment including playing game with children for sign language teaching is the basic motivation of this study. To achieve this, child-sized humanoid robots with high degree of freedom (DOF) in arms and fingers are being used in sign language based interaction games [18-20].

1.2 Sign Languages

SL is a visual language that is composed by a combination of hand gestures, facial expressions, and head movements. Sign language is the basic communication medium for the hearing-impaired people. The common property of sign languages are that they are all visual language and each sign language has its own grammar and rules. Signs are used in a sign language to establish a communication with words and sentences to audience. Words have corresponding signs in a particular sign language and each letter also has a sign to perform words that don't have a corresponding sign in that sign language.

1.2.1 Turkish Sign Language

Turkish Sign Language (TSL) is a visual language used by the hearing-impaired community in Turkey. The language has its own alphabet, vocabulary and grammar structure. TSL provides non-verbal communication through hand gestures and facial expressions. Despite some regional dialectal variation, the language is used all over Turkey. Hearing-impaired people from different regions of Turkey are able to communicate with each other using TSL [21].

The history of TSL dated from 15th century, when the hearing impaired people were called "mute"(dilsiz). They were taken to Ottoman Palace in the period of Fatih Sultan Mehmet to provide information security and to entertain Sultan. They were employed in the palace in the beginning, later on, starting from 18th they were hired Bab-ı Ali. They took place in the secret sessions in Meclis-i Has. According to Miles [22], TSL has become a communication system, which could state complex concepts in at the beginning of 17th century. In the memories of Bobovius, it was emphasised that TSL became a prestigious secret language in the 17th century [23]. In the

Ottoman Palace, TSLwas not only used by hearing-impaired people but also used by women in the harem and also used by sultan in the personal communications. It was a multipurpose, secret and prestigious language.

1.3 Problem Definition

Teaching sign language is an important and difficult task. Hearing impaired people need to learn sign language to communicate easier. One of the difficulties in teaching sign language is that the need of repetitively practice and receive feedback frequently. Nevertheless, each sign language tutor has a different style, which sometimes causes difficulty in learning in case the instructor is replaced. It is intended to employ humanoid robots as a sign language tutoring assistants. The usage of humanoid robot as a sign language tutor serves as a fast, simple and motivating tool that can be easily updated to teach and practice sign language to children with different disabilities. Automation of the teaching sign language is achieved with different methods in several research projects such as web based sign language tutors [24], sensor glove based sign language tutors [25] and robotic hands as sign language tutors [26, 27]. Despite of these research attempts in sign language tutoring, the amount of educational material is still not sufficient. This thesis aims to utilize humanoid robots for aiding sign language tutoring due to the difficulties with 2-D instructional tools developed for this goal and the lack of sufficient educational material. In the proposed work, a child-sized humanoid robots will perform various elementary SL words to assist teaching these words to hearing impaired children. The system will be easily adaptive in children's disability degree. This will be achieved using interaction games based on non-verbal communication, turn taking and imitation, designed specifically for the robot and child to engage each other in play. As a starting point, we designed a series of user studies to answer the following research questions:

- Are the learners' competence, performance and interest of learning sign language improved when humanoid robots are used to teach SL? Does a humanoid robot and a human tutor affect learners' performance of SL equally?
- Are using humanoid robots and interaction games to teach SL motivate participants in learning SL?

- Do the learners enjoy while learning sign language via interaction game with the humanoid robot? Do the interaction games ease the learning process?
- Does the usage of humanoid robots ease the learning process of sign languages?
- What is the effect of using humanoid robots and interactive games in the sign language learning? Do the interaction games advance the learning?
- What is the best experimental setup for children to teach sign language?

1.4 Overview of the Thesis

Chapter 2 provides literature review including the usage of robots as therapy tools, the research overview about sign language recognition and realization, the interaction games in the literature for children by using humanoid robots, language acquisition, humanoid robots usage in sign language teaching researches and the chapter concludes with the cognitive development of hearing impaired children. Chapter 3 provides the proposed method. The chapter starts with introducing the humanoid robot Nao H-25 and the humanoid robot Robovie R3 that are hardware platforms in this thesis, and continues with introducing software platforms.The software platforms used in Nao robot are Choregraphe software and Naoqi software development kit (SDK) and the software paltforms used in Robovie R3 are RobovieMaker2 and VSRC003 SDK. The chapter also discusses the implemention of signs. In this chapter, two frameworks are presented. One of the frameworks is the implemented framework in this thesis, the other is the complete framework, which will be completed as a future work. The chapter discusses the proposed modes that consists of three parts including introduction, reinforcement and interaction games. The modes are described in detail in this chapter. Chapter 4 discusses the conducted experiments and their results. In this chapter experiments are presented in a systematic way including hypothesis and research questions, participants and sample, experiment set up and results. Chapter 5 provides the conclusions and futurework.

2. REVIEW OF LITERATURE

In this chapter we review some of the studies which provide basis a background for this thesis. This chapter examines the robots as therapy tools, sign language recognition and realization, interaction games, the usage of robots as sign language tutoring assistants and the cognitive development of hearing impaired children.

In the future, humanoid robots will become essential part of our daily lives similar as computers and internet. Service applications of humanoid robots will increase in environments like homes or offices in daily routines such as education of children, entertainment and caring elder people. Humanoid robots resemble humans in many aspects including appearance, sociability, personality and statement of emotions [28]. According to [29], in human computer interaction user features such as age, gender and personality are crucial viewpoints. User attributes must be taken into account while designing interactions with a humanoid robot. The perception of humanoid robots as peers by humans is an important issue to make humans feel comfortable in interaction with robots. Therefore, the studies of human robot interaction should take the issue of being socially acceptable into consideration.

2.1 Robots as Therapy Tools

The study in [30] disscusses the usage of humanoid robots as therapists. According to [30], main features of a therapy robot are mechanical compliance, the capability of completing desired movements and needing minimum assistance while providing help, it should have adaptive assistance properties. The humanoid robot-therapist should have sensor-motor intelligence and it should be adaptive-cognitive capable. Flexibility of humanoid robot therapist is important in case of adaptability of patient task and robot task. In [31], a research was done to understand the impact of using humanoid robots as personnel in clinical and nursing situations. A survey has been conducted among hospital personnel to learn their ideas about use of humanoid robots in hospitals to deal with personnel shortage and reduce the workload in nursing. One of the obtained results showed that medical staff do not have enough information about humanoids. Robots as pets and toys improve the condition of subjects. Humanoid robots can be used in the area of nursing care. In [32], a face detection method proposed for face tracking in robotic assistive therapy to children with Autism Spectrum Disorder (ASD). In this study, humanoid robot Nao was used and the reactions of children were recorded. The interaction time between humanoid robot and children was considered to evaluate the concentration level of those children. In [33], a new robotic platform is introduced for autistic children which is affordable, non-threatening and with the ability of interaction. The designed robot named as PABI, is used for robot-assisted therapy. It is planned to have applications such as automatic repeatable sounds and gestures producing, recording the reactions of children, that can be tele-operated from a professional. In [34], a hypothesis is proposed that using robots in rehabilitation can improve the therapeutic outcome. The applications will be adaptive in terms of patient's movement and intention in the future.

2.2 Recognition of Sign Language

In sign language teaching and learning, sign recognition plays an important part. Various studies have been carried out for the recognition of different sign languages. Either finger or hand gestures are used in these studies, tested with different cameras and different approaches [35, 36]. In 1998, two real-time Hidden Markov Model (HMM) based systems were presented first, during the tests, the camera for capturing the signs was mounted on the desk in front of the user and achieved 92% word accuracy. Secondly, the camera was mounted on the cap worn by the user and achieved 98% accuracy [37]. In [38], study on French Sign Language, prologue and epilogue gestures were tried to be minimized with using coarticulation parameters. In [39-41], both recognition of hand shape and movements, and analyzing facial gestures studies were carried out for languages TSL and American Sign Languages (ASL). In 2002, a study stated that recognizing sign language gestures using sensor gloves was possible [25]. The study in [42] presented a set of algorithms designed to recover the 3D position, hand shape and motion in order to represent and interpret the signs in the ASL whereas in the [43], authors presented a combination of vision based features such as hand shape, place of articulation, hand orientation, and movement in order to enhance the recognition of underlying signs. In [45], a method to recognize hand gestures in a continuous video stream using a dynamic Bayesian network was proposed, and a gesture model for one and two-handed gestures was developed. On the other hand, there are studies focusing on the facial expressions used in sign language communication in order to capture the non-manual cues [46], as well.

2.3 Realization of Sign Languages

The realization of sign language researches are few because two human-like hands are necessary. In 1984, a robotic hand has been developed but it was a single hand arm with difficult configuration [26]. In 2002, robot hands have been designed with the purpose of the human mimic task implementation and especially for sign language realization [27]. These robotic hands were used for Japanese sign language realization which can perform 16 Japanese sign language words and 3 Japanese finger alphabets [27]. In these studies, the robotic hands were not connected to a robot and hands were not enough for sign language, which involves the simultaneous use of both manual (hand configuration, orientation, placement or movement) and non-manual (posture of upper torso, head orientation, facial expression, and gaze direction) components [47].

Different groups are working on controlling environments or robots with sign language [48, 49]. In [48], several symbols of the Mexican Sign Language alphabet are assigned to tasks for the robotic system with eight different tasks. There are several studies for sign language generation with robots, as well. Various studies have been carried out for the teaching of sign language via the information technologies to facilitate the learning process. The study [50] presented an adaptive web-based system, Kids Sign Online specifically designed to teach British Sign Language. The system used adaptive learning strategies together with digital video, presented by deaf children, for deaf children, to facilitate learning. The use of 3D application is also very common in the teaching of sign language; in [51] they implemented a multimedia environment using mainly as web-based tool, which permitted to interpret automatically written texts in visual-gestured-spatial language using avatar technology, whereas [52] presented an avatar-based application implementing the upper body movements, hand shape and arm movement with fluent expressions.

2.4 Interaction Games

In HRI, social interaction with inexperienced users is increasing. Design of interaction environment that users feel comfortable is an important issue. If the robots behave the humans as partners, the interaction becomes social. Social interaction with robots and children with different levels of disabilities can be very helpful for children' therapy. The interaction games are getting popular in the HRI context. There are several successful user studies on non-gesture communication through imitation based interaction games with humanoid robots and human participants [53, 54]. The study in [53] implemented the rock, paper, scissor game; and in [54] they described a data collection experiment based on an interaction game inspired by "Simon says" where the turn taking was engaged by gaze, speech, and motion. They discussed how to implement their founding into a computational model of turn taking. On the other hand, in [55], an affective modeling methodology was presented which was tested with a robot-based basketball game. The presented methodology allowed the recognition of affective states of children with ASD from physiological signals in real time and provided the basis for future robot-assisted affect-sensitive interactive autism intervention. In another study, an interactive program was presented in order to teach mathematics to hearing-impaired children by the use of a 3D animation [56].

In 2004, an experiment took place in 2 weeks period in a Japan primary school [57]. This study searched the interaction between robots and children and the idea of learning from robots. Our work also explores the idea of learning from robots; this work can be a guideline for learning from robots. In two weeks period, 2 robots talking English placed next to first classes and sixth classes in a Japanese primary school. Through wireless tags and sensors, the robot could recognize the children. At the beginning of the study, after first week and after second week, children tested by matching the pictures with words. Tags, cameras and voice records recorded children interaction with robot. The large part of the interaction between robot and children, there were more than one child (children were generally available with their friends.) The interest to the robot was considerable high in the first week but it decreased significantly in the second week. The comparison between first week test and second week test showed that the children who continued to interact with the robot learned more. If the child had pre-knowledge of English or child had interest to learning

English, the learning rate from the robot was increased. Japanese children were not motivated to learn English. This study was held with a primary school and Wakayama University. The robot recognised the child on his/her id tag and initiated the interaction by calling the child using his/her name. The robot only spoke English and its voice was child-like voice. Each child had a tag and this tag sent its id to the embeded reader on the robot. The reader sent ids to software and interaction history was saved. In 1996, a linguistic study carried out and in this study, in the communication process, humans are categorise into two: participants and audiances [58]. In this study, the robot could distinguish the participants and audiances from the distance. By refering [59], if the children are in a close proximity between 0-1.2m they accepted as participants and proximity between 1.2-3.5 accepted as audiances. In human-robot interaction, average distance is 0.5m [60]. The robot had 100 interaction behaviors. 70 of them were behaviors like handshaking, paper-scissors-stone ball, greeting, kissing, singing, speaking briefly, point out something. 20 of them are behaviors like scratching its head, fold its arms like behavior, reminder 10 of them behaviors like floating around. The robot could recognise about 50 English words and it could speak more than 300 sentences. If the child was close to the robot, the robot could perceive the child by reading tag. The robot could play with child, it could inititate the intreaction by saying, and “let’s touch me” The interaction duration between robot and children was saved by software for each child. For validating the tag, camera records and microphones were used. The children performed three English tests; each test included same questions with different order. In the tests, children listened an English speaker and choose one picture among four pictures. The children surveyed by asking their friends and this survey was compared with robots interaction logs. These applications helped to understand interaction duration between robot with child’s friends. In general, there was no major development in English knowledge of children but the children who continued to interact with robot in the second week improved their English knowledge. In total, first classes spent more time with robot than sixth classes but in both categories, interest in robot was decreased visually in second week. While children spent time with robot, they had friends with them and this affect the English learning rate of children. Learning from robot requires the interest and interaction persistence. Pre English knowledge affected the interaction positively, the children who had English knowledge find a common ground with robot and it increased the interaction with robot. If the children had a little English knowledge, they learnt much from the robot. This condition supported the idea in psychology literature that is common points and similarities ease the communication. The robot’s effect depends on devoloping interaction between users and the effect of the robot can change in time. Effective robot parnerts can be developed by long-term interactions. Calling the children by their names affected the interaction positively.

In 2012, a long-term experiment was done with Nao robot for analyzing children behaviors, interest and entertainment [61]. In this experiment, 19 children with ages 5 to 12 years accompanied and played three games with Nao robot including dance, imitation and quiz. The main aim of the work was to examine how children behave to the robot. In the dance part, children stood and learnt to perform the movements from the robot. In the imitation part, the robot and child realized a group of gestures in turn. In the quiz part, unlike other parts children sat down and interaction in this part was verbal. The child could quit interaction whenever he/she wants. In each part, child spent alone one hour with robot.

2.5 Language Teaching and Communication

In [62], baby sign language is introduced. Teaching sign language to the babies is very important for their cognitive, language and emotional development. Babies have some hand gestures that are seen towards the end of first year. Teaching sign languages to the babies is adding new gestures to existing intuitive gestures. While teaching signs to the babies, the biggest advantage of usage of real sign language is every word has a correspondent sign. Sign language knowledge of babies very helpful for emotional development babies share their needs easily and establish better communication with their parients hence they cry less. It is a very effective method for development of the brain doing unusual things. Babies from their six months can learn sign language. Parents can select some very common words both saying and expressing signs and pointing the object can be effective for sign language teaching. For adding new words, parents should wait until baby learns the signs. While teaching signs to the babies, showing object and saying meaning of sign is important these helps baby to learn meanings of expressions. In sign language teaching, expressed word should said stressed and exaggerated. Giving positive feedback to the babies motive them to learn and to express signs. If the baby expresses the signs wrongly, not to correct him/her is important in case of baby's motivation.

Positive feedback improves personal development of babies. Children love dancing with music, teaching sign language accompanied with music seems as if a play and increases the child's performance. Using music in teaching is also important for brain cells development.

The study [63] introduced teaching language to the robot. 14 months human child babbling is important for linguistic skills development [64]. This study used the idea of babbling importance in learning language in human child as a starting point. According to recent neuroscientific research, language processing requires dual systems such as ventral pathways and dorsal pathways [65, 66]. This work depended on analogy of dorsal pathway. Human teachers interacted with iCub robot with the aim of teachig some words. In the experiments, teachers used their own words while talking with robot. The experimental scenario takes place as follows: human teacher was given some shapes with different colours and tried to teach them to the robot as if it was a little child. In the experiments, 34 participants with various background took role. Robot had some gestures like turning its head, moving arms, a little smiling and blinking eyes. Robot received the speech as a stream of phonemes and phonemes segmented into syllables with any segmentation knowledge. Stream of phonemes segmented to all possible syllables. At the beginning of the interaction robot babbled random syllables but during the interaction progress, it learned from the human teacher. The human teacher talked a stream of phonemes; the robot took this using a speech to text tool. The robot segmented it to all possible syllables and selected randomly one of these syllables. The robot babbled the syllable, teacher listened the syllable and gave feedback to the robot and if the syllable was correct, it was added to the lexicon.

In [67], visualiton of verbal expessions for the aid of supporting and helping autistic children and children with mental disabilities to understand a Turkish expression. The system consists of four modules. The designed system's graphical user interface module inputs a natural language sentence and offers a picture that represents this sentence.

In [21], aspects of Turkish Sign Language is examined. This study was about TSL grammatical structure. TSL is used in all over the country (Turkey) with some regional accent differences. TSL derived from another sign language or affected strongly from another SL. Community of deaf people organized centrally. All relevant associations are organized under the umbrella of “Turkey Hearing Impaired Federation”. This study focused on hearing impaired community and their problems. Three TSL signs (OKAY, DONE and TO BECOME) were presented. The place of these words in TSL and head and body gestures to realize these signs were also mentioned. The importance of TSL definition and documentation were emphasized.

In [68], an experiment with teleoperated communication robot was introduced. The main aim of this paper was to produce communication robots; in daily activities, human-robot interaction was searched. The robot was tested in laboratory but it can encounter unusual situations in real life, to prevent this shortage they developed a semi-automatic robot. Speech module of the robot was managed by a human operator. Some simple conversations were provided by software. The robot used a map of mall to guide and it had functions like information services. Movement and control behaviors were provided with wireless network. The operator watched the camera captures that were located inside the shopping mall and listened the sounds and operated the robot. In the teleoperated room, there were four monitors for watching camera records and a computer for operating the robot. The computer and the robot connected each other via wireless network. The camera record and command history saved in a database. For sound transmission, they used IP telephone on the robot. The participants of the experiment were 3 women and 3 men (in twenties) and they did not familiar with the shopping mall. The experiments were done in late hours. The robot had 10 behaviors. The users filled out a survey. They gave positive feedback about all modules except the greeting with name. The studies with children showed that children like calling by their names but adults in shopping mall did not like greeting with name. The speech delays in the robot were also evaluated negatively.

2.6 Using Robots to Perform Signs

In the studies [18, 19, 69-73] humanoid robots were used as sign language tutors. In these studies, interaction games motivated children to participate the learning process and the experiments provided comfortable and enjoyable learning environment. In [18], several surveys and user studies were proposed based on sign language performed by a humanoid robot. In this study, the performance of the robot was evaluated using the surveys and user studies, where the videos of real/simulated Nao H25 robots realizing several selected signs. The participants were asked to fill out a questionnaire in order to assess the resemblance between the robot and the human teacher to determine whether the Nao robot had a similar success rate as a human tutor in expressing sign language. Within this study, TSL was being used and 5 words were voted, the survey was carried out through three user studies. First group consisted of university students who have little or no acquaintance with sign language. The second group consisted of university students from the sign language classes of two different universities. Lastly, third group preschool children from a collaborating nursery, participating the study using a simpler version of the web based survey (less verbal, mostly sign and picture-based explanations).

In [70], also introduced sign language teaching by means of interaction games with humanoid robots to the hearing impaired and autistic children. Several types of media including robots with different embodiment, tablets, and web based applications were being used within the study. The game was based on the visual cards, the cards were shown to the robot to select among several signs from ASL and basic upper torso motion (hands side, forward, up) The robot performed the sign and waited for the child to imitate. The imitated action was evaluated using an RGB-D camera (Kinect) and robot gave a motivating comment when the action was imitated with success. The experiments were being conducted with adults, sign language students, children with normal development, hearing impaired children and children with autism. The main aim of this interdisciplinary study was to build a bridge between the technical know-how and robotic hardware with the know-how from different disciplines to produce useful solutions for children with communication problems. In this paper, 6 HMM belonging to 6 signs were trained with 180 training sample and tested with 125 test samples. The K-Means method was used for data clustering.

In [19], an interaction game was designed including the words and signs from previous study with adults. The implemented story telling game was partially in sign language, where the children interacted with the robot and assisted the robot with colored flashcards to indicate correct words matching the robot's signs throughout the game. The game was tested with 106 preschool children in a nursery. The children did not know sign language before, and they were not hearing impaired. The obtained results show that even if the robot had physical limitations, if the education was given within a relevant context/story that is also interesting and suitable for this age group, the success rate increased significantly. The results proved that study can be applied to the other education projects for the disabled children, as well.

2.7 Hearing Impaired Children Cognitive Development

Developmental process of social learning starts with birth by being a member of a family, and with growth, human being becomes a member of society [74]. In this process, human being gains experience and learning opportunities, that called as socialization process and it is important in social and personal behavior [75,76]. According to [77, 78] social interaction plays a critical role in learning. According to Vygotsky's Social development theory [77], cognitive development of a child advances with social interaction. The study [78] emphases that social interaction and collaboration plays a critical role on learning. They argue that self-improvement develops with face-to-face interactions. The social relationships arise in the child's family and expands with growth to friends and school [76]. Hearing impaired children suffer from social relationship establishment which causes a delay in their cognitive development and obstructs social learning. Hearing impairment is not an insufficiency on learning, hearing impaired children need to support from their family and school for their development [79].

According to research conducted in [80], the math computation skills comparison between hearing children and hearing impaired children at the age 15-year-old showed that lack of hearing does not affect the performance on symbolic knowledge. Another research showed that hearing impairment has great effect on reading and writing skills negatively. The degree of hearing impairment is directly proportional to the reading ability [81]. There are other findings in [81], which state hearing-impaired children whose parents know sign language and use sign language at the children early ages (3-year-old or before) have higher level reading skills. The studies researching the relation between sign language knowledge and reading development showed that even though ASL and spoken English grammar and linguistic differences, sign language knowledge has positive effect on reading development [81]. There is a positive correlation between ASL performance and reading achievement [81]. Having a well-developed primary language provides a basis on reading learning in hearing-impaired children [81].

Language development in hearing impaired children is incomplete and is affected negatively by not to receive verbal language input and hearing impaired children's language development differentiates by the aspects of understanding and generating language [81]. Speech creation of hearing impaired children basically depends on children's degree of deafness, nonverbal IQ and socioeconomic status [82]. For the hearing impaired children cognitive development, they need to have a complete language knowledge. Hearing impaired children's handicap is obtaining language which includes vocabularies, morphology and syntax from this point of view, acquiring a sign language in early ages has great importance [81].
Hearing impaired children vocabulary acquirement is delayed, the studies are done for English showed that learning sentence structure of hearing impaired children are correlated with hearing levels and another finding of these studies showed that hearing students and hearing impaired students have similar trouble in English syntactic structures [81]. Getting a primary language for hearing impaired children is difficult and they have also difficulty in learning grammar both in reading and writing [81]. Language teaching is best in early ages, acquiring a language in early ages known as *critical period*, the delay in primary language acquisition in early ages can result with permanent deficiency [81]. The project aims to compensate this deficieny by generalizing the usage of humanoid robots in sign language teaching.

Interaction between humans is multi-modal that means interaction includes both verbal and nonverbal gestures [74]. The environment of human beings affects the shape of interaction and the variety of social behavior directly related with the society [74]. In the society, the behaviors of human beings may seem very complex to the children with communication problems [74]. The robots can provide more simple interactions and the complexity of interaction can be changed by programming. Interaction between robots can be controlled and arranged for suitable interaction environment. [74].

In social learning, imitation has great importance [83]. Besides being an important learning tool, imitation helps people to understand the society. [84,85]. The observation of social world around us provides guideline and pre-knowledge to the human beings for later behaviors [74].

According to Vygotsky's Zone of Proximal Development (ZPD) theory, learning can only occur if the child interacts with the environment and collaborates with others [77]. Vygotsky also highlights that playing a game is an important activity for children both for their development and creativity [77]. There are other researchers who put emphasis on play activity in the children development and socialization [86,87,88]. Learning some concepts within a context can be very helpful for children socialization and creativity. By using a robot, different types of interaction can be produced for children. In the interaction with robots, the system can be designed adaptable to the interaction cases according to the children. The degree of interaction complexity can be changed according to children capability.

In the communication, using an embodied robot can engage the children for interaction establishment, it also provides a perception of physical existence of full body that cannot yield with a two dimensional tools such as computers [74]. Using a robot as a therapy tool gains the children understanding of social interaction with others [74].

3. PROPOSED SYSTEM

The main aim of this study is using humanoid robots as sign language tutoring assistants to help the children with different communication problems especially for hearing impaired children. In the current system, we investigate two types of humanoid robots and the effect of their different features such as size, finger dependence and appearance on sign language teaching. The sign language teaching progress is supported with interaction games between children and two type of humanoid robots that are Nao H-25 and Robovie R3.

3.1 Humanoid Robot Nao H-25

In 2005, French company Aldebaran Robotics manufactured a humanoid robot that could be bought for a reasonable price, provide multiple features and with easy but efficient usage. In 2007, Nao humanoid robot was substituted the Aibo in the RoboCup worldwide robot soccer contest [89].

We preferred Nao H-25 humanoid robot from this robot series in this study due to its small, lightweight and compact hardware and easiness to use within field experiments with children. It has 25 DOF, 11 DOF for the lower part these are 2 DOF at the ankle in each leg, 1 DOF at the knee and 2 DOF at the hip, legs and pelvis, and 14 DOF for the upper part these are trunk, arms and head [6]. Each arm has two DOF at the shoulder, 2 DOF at the elbow, 1 DOF at the wrist and one additional DOF for the hand's grasping. These joints can bend 45 degree towards the body. The robot head is also moveable, it can rotate about yaw and pitch axes, and each joint has position sensors. It has input devices that are two cameras (640x480), four microphones and tactile devices, the robot's tactile devices provide to communicate with Nao. Microphones gives a natural way to convey information with Nao, its output devices are two loudspeakers and programmable LEDS around the eyes. Lithium Polymer batteries supply power to the Nao, duration of the battery changes between 45 minutes and 4 hours, Nao actuators use precise and reliable motors, the operating system of robot based on Linux, controlling robot and the software maintenance is easy and customizable, the robot has a rich development environment [6].

It is a small sized robot with a height of 0.57 m and a weight of 4.5 kg. It is a biped robot and due to its lightweight makes it less dangerous and less to breakdown. It can perform precise, smooth and autonomous movements. Modularity is an important characteristic of Nao, modular design of robot’s joints are useful for robust movements. The head, hands and forearms can be changed. It has x86 AMD GEODE 500 MHz CPU motherboard with 256 Mb SDRAM on its head. There is additional 1GB flash memory. Communication with robot can be establish through the WiFi or Ethernet port. In the robot’s torso, one ARM7-60MHz microcontroller is available which distributes information to all the actuator module microcontrollers [6]. Having 2 gyrometers and 3 accelerometers, and 4 Force Sensitive Resistors under each foot gives estimation capability of current state to Nao. Using the sonars, the robot can measure the distance between its environments [89]. Obstacles can be detected by the bumpers on the robot’s feet. Nao has its own programming tools; Naoqi and Choregraphe. The components names of humanoid robot Nao can be seen in Fig. 3.1.

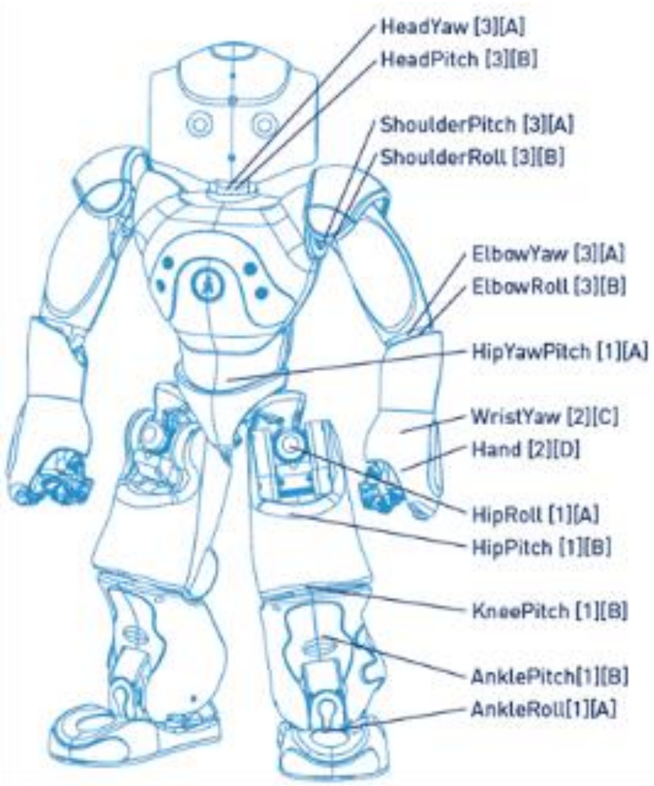

Figure 3.1: Nao H-25 humanoid robot components names [90].

3.1.1 Choregraphe

Naoqi is a framework that allows accessing all the features of the robot; it provides communication between distributed binaries and their modules. Choregraphe is a Naoqi module with graphical environment for programming Nao. It is the programming software; users can create and edit movements and interactive behavior with it. It provides to control motions simply and efficiently that allows user to rapid development. Choregraphe is able to perform fine-tuning of complex joint or Cartesian motions. It has well designed user interface, standard behavior library, and users have flexibility to write their own boxes by writing Python scripts. Users can design their programs by event-based, sequential, or parallel programming. It also provides the timeline that lets users create their programs within schedule logic. Users have huge opportunity by using the combinations of these approaches in NAO programming. It is also ability to call separately developed C++ modules. Using Choregraphe, one can access all the functions of Naoqi. A cross-platform software means it can run on different operating systems. It can run on several platforms (e.g. PC, MAC and Linux).

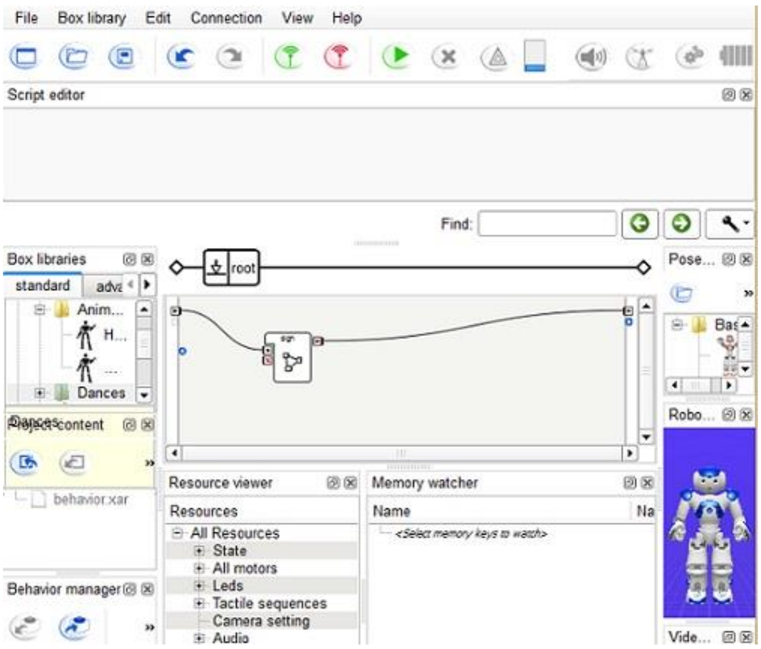

Figure 3.2: Choregraphe Software GUI.

Users can create behaviors using Choregraphe. A behavior is software piece that can control the robot. There are some predefined behavior boxes in Choregraphe, but users can also create a new box and add it to the current library. Behaviors can be connected sequentially or parallel and it is possible to test the program on the virtual Nao on Choregraphe. In the programming process, time control is achieved by timeline on Choregraphe. By using timeline, user can describe the duration of each behavior and can change joint angles to create a desired behavior. Nao humanoid robot joint orientation and angle limitations are given in Table 3.1. Some modules of Choregraphe cannot run on virtual robot, regarding this feature it is not a full simulator [90]. Users can access all the API of Naoqi by using Choregraphe but behaviors programmed with Choregraphe are slower than the behaviors written in C++.

Table 3.1 : Nao humanoid robot joint orientation and angle limitations.

Joint Name	Motion Plane	Angle Limitations
Left Shoulder Pitch	Left shoulder joint forward –backward (y)	-119.5 – 119.5
Left Shoulder Roll	Left shoulder joint left – right (z)	-18 - 76
Left Elbow Yaw	Left elbow joint rotation (x)	-119.5 – 119.5
Left Elbow Roll	Left elbow joint (z)	-88.5 - -2
Left Wrist Yaw	Left wrist yaw (x)	-104.5 – 104.5
Right Shoulder Pitch	Right shoulder joint forward –backward (y)	-119.5 – 119.5
Right Shoulder Roll	Right shoulder joint left - right (z)	-76 - 18
Right Elbow Yaw	Right elbow joint rotation (x)	-119.5 – 119.5
Right Elbow Roll	Right elbow joint (z)	2 – 88.5
Right Wrist Yaw	Right wrist yaw (x)	-104.5 – 104.5

3.1.2 Naoqi

The main software runs on the robot is called Naoqi. Naoqi allows controlling robot and accessing all the features of the robot. It provides homogeneous communication between distributed binaries and their modules (motion, audio, video etc.) It also has features like parallelize and synchronize the modules. Naoqi is a cross-platform and cross-language software (supports different programming languages). To use all Naoqi modules, a program can be written in C++ or Python. In Nao programming with C++, a module can be local or remote. Remote modules are compiled as an executable and they can run without uploading the robot. They are less efficient in memory usage and speed by comparing local modules. Remote modules do not allow direct access to the robot's memory. Local modules are compiled as a library and they are loaded to the robot in startup. By using local modules, one can access to the robot's memory and can reach the values obtained from robot sensors (cameras, tactile sensors, microphones etc.).

In this thesis Naoqi modules; ALMotion, ALBehaviorManager, ALMemory, ALTextToSpeech, ALFaceDetection, ALVisionRecognition, ALSensors and ALLEDs are used. These modules are parts of fundamental functions provided with Naoqi.

3.1.3 Naoqi software developmant kit (SDK)

Naoqi SDK allows users to write their own codes using C++ or Python. Naoqi API supports some other languages but they are allowed to access remotely to the robot. In this thesis, we used Naoqi-sdk-1.14.1-win32-VS2010. For development environment some other software requirements are:

- CMake 2.8 win32 x86 (required for cross compile)
- VS2010 (development IDE)
- Python-2.6 (required for SDK)
- Choregraphe-Suite-1.14.1-win32-setup (required for testing codes on simulated robot)

3.2 Implementation of Signs on Nao H-25 Humanoid Robot

The words that are used in this thesis are selected from the Turkish Sign Language Dictionary [91] in terms of the physical limitations of Nao H-25 humanoid robot. The robot has three dependent fingers so the signs that can be implemented within this limitation are selected. As a next step, the selected signs are implemented on the robot using Choregraphe software. A box that includes timeline called Timeline box. In Choregraphe, timeline boxes are used and more than one hundred signs are implemented by changing joint values of robot manually. It is also possible to export C++ codes of timeline boxes. Figure 3.3 shows Timeline Box on Choregraphe. Manual sign implementation is time-consuming job.

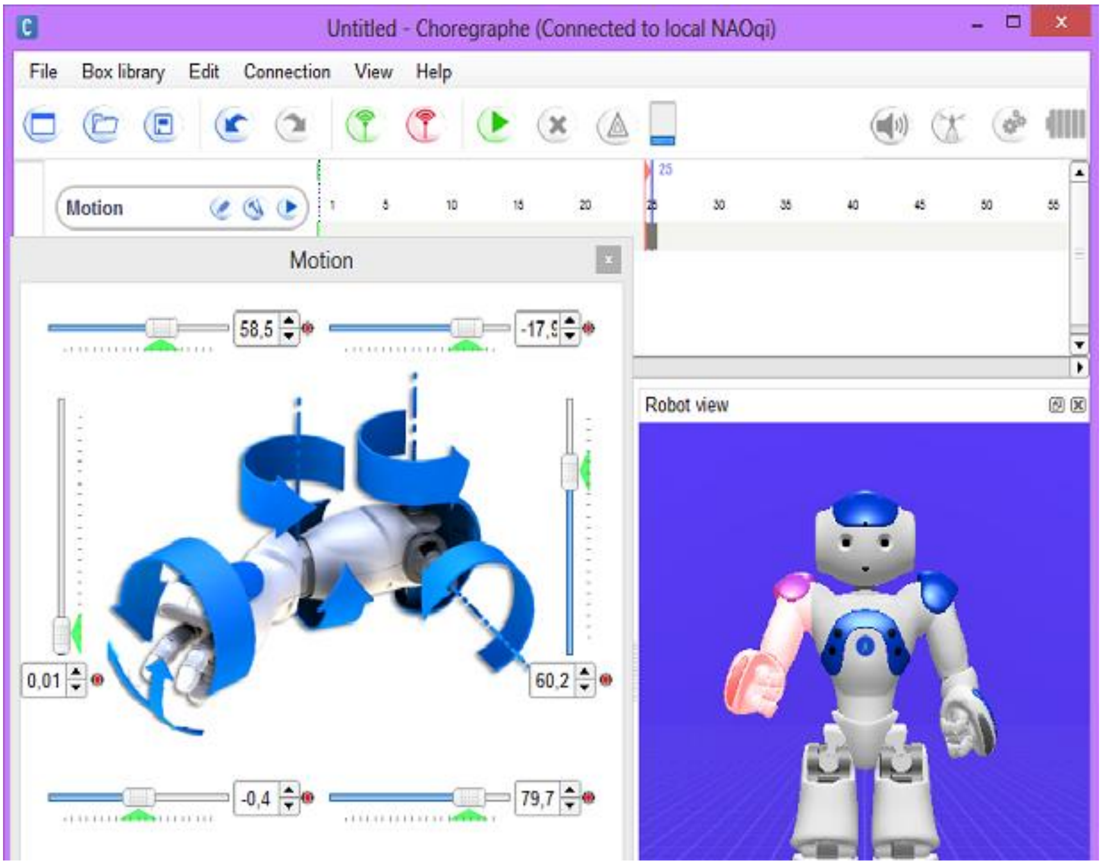

Figure 3.3: Timeline box.

We implemented more than one hundred words from Turkish Sign Language on Nao robot. The implemented signs were observed and verified by experts of sign language, and robotics and the ones which were dangerous to implement on the real robot and the signs which could not be recognized were eliminated from the study. The best 91 selected words are shown in Table 3.2. Nao has heating problem so performing all signs in one session is not possible. The system is adaptable to new words. Some TSL words are shown in Figure 3.4, the signs are to get hungry, to throw, to wait, spring and big respectively.

Figure 3.4: Nao robot implementing TSL words.

Table 3.2 : Selected words on Nao H-25 from TSL.

	Turkish Word	English Meaning		Turkish Word	English Meaning
1	acıkmak	to get hungry	47	ense	nape
2	ait	belong to	48	eşmek	to dig up
3	alan	area	49	ev	house
4	alışveriş	shopping	50	evet	yes
5	alkış	clapping	51	gelmek	to come
6	almak	to buy	52	geniş	large
7	alt	bottom	53	getirmek	to bring
8	alçak	low	54	hafif	lightweight
9	ampul	bulb	55	hala	aunt
10	anlamak	to understand	56	halı	carpet
11	anne	mother	57	hayvan	animal
12	apartman	building	58	kabul etmek	to accept
13	araba	car	59	küçük	little
14	arka	back	60	lamba	lamp
15	atmak	to throw	61	masa	table
16	ayran	buttermilk	62	okul	school
17	baba	father	63	sabun	soap
18	bahar	spring	64	sahip	owner
19	bahçe	garden	65	sahur	sahur
20	balon	baloon	66	saksı	flower pot
21	ben/benim/bana	me/my/mine	67	sallamak	to shake
22	bayram	festival	68	sarılmak	to hug
23	bebek	baby	69	sayın	honorable
24	beklemek	to wait	70	selam	greeting
25	beraber	together	71	sevinç	happines
26	beşik	cradle	72	seviye	level
27	biz	we	73	sevmek	to like
28	bölme	division	74	sihir	magic
29	bozmak	to ruin	75	sihirbaz	magician
30	büyük	big	76	silmek	to erase
31	çalışmak	to work	77	sinema	cinema
32	çarpışma	collision	78	siyah	black
33	çatı	roof	79	sol	left
34	cesaret	courage	80	sonbahar	autumn
35	çevre	environment	81	süpürge	sweeper
36	çiçek	flower	82	sürekli çalışmak	to plug away
37	çizgi	line	83	tabiat	nature
38	çok	very	84	tamam	okey
39	çorba	soup	85	yıkanmak	to bath

Table 3.2 (continued): Selected words on Nao H-25 from TSL.

40	dans	dance	86	yıkmak	to collapse
41	dar	narrow	87	yokuş	slope
42	dağ	mountain	88	yol	way
43	değil	not	89	yumruk	fist
44	dolap	wardrobe	90	yüzmek	to swim
45	durmak	to stop	91	güzel	beautiful
46	elma	apple			

3.3 Humanoid Robot Robovie R3

Robovie R3 is a specially modified version of standard R3 humanoid robot. Standard R3 platform is 1.08 m tall and weighs 35 kg and has 17 DOF (2*arms*4, neck*3, 2*eyes*2, wheels*2). Our version of R3 robot has additional DOF in wrists, and fingers, 29 DOFs in total. Also our robot has a LED mouth to express gestures better. As it has 5 fingered hands, it is easier to implement accurate signs with fingers moving independently. It has a small platform on the chest which is used to integrate a ASUS RGB-D camera for gesture recognition. This camera can be replaced with a touch pad tablet according to the scenario of the game. It is a child-sized humanoid robot and is convenient for interactive games for children since they consider the robot as a peer.

For controlling Robovie R3 robot, we can use RobovieMaker2 software or VSRC003 SDK. Figure 3.5 shows Robovie R3 robot implementing signs, arms side and big respectively.

Figure 3.5: Robovie R3 humanoid robot.

3.3.1 RobovieMaker2

RobovieMaker2 is a software that is used to control board, "VS-RC003" which is the control board on Robovie R3 robot. By using this software, servomotors, controllers and expanded boards settings and preferences can be changed. The RobovieMaker2 has also a GUI to create motions. The software also provides to play the created motions on the robot. Figure 3.6 shows the five-fingered hand of Robovie R3 robot. It is possible to load motions to the servo motor controller which enables to control the robot by using remote controller or autonomous movement. In figure 3.7, a screen shot of RobovieMaker2 software is shown. The software has "Pose area" and "Motion area". By using the "Pose area", we can decide the current pose of the robot and by using "Motion area", we can assign poses to time sequences. In the "Motion area", setting of pose speed is also possible by arranging the pose time.

Figure 3.6: Five finger hand of the humanoid robot Robovie R3[95].

3.3.2 VSRC003 SDK

VSRC003 SDK which R3's own software development kit lets user to upload, play, stop, and cancel motions, check the status of the motion and servo power switch. It is also possible to read and write memory cells of the board and joints control in real time.

3.4 Implementation of Signs on Robovie R3 Humanoid Robot

Our version of Robovie R3 humanoid robot has five fingers in each hand and the fingers can move independently so the robot can implement most of signs from TSL. We implemented 13 signs from TSL on Robovie R3. The implemented signs list is given in Table 3.3.

Table 3.3 : Implemented TSL words on Robovie R3

Turkish sign	English meaning	Turkish sign	English meaning	Turkish sign	English meaning
İlkbahar	Spring	Anne	Mother	Siyah	Black
Atmak	to Throw	Lamba	Lamp	Dağ	Mountain
Ben	I / Me	Baba	Father	Masa	Table
Büyük	Big	Araba	Car	Gelmek	to Come
Bebek	Baby				

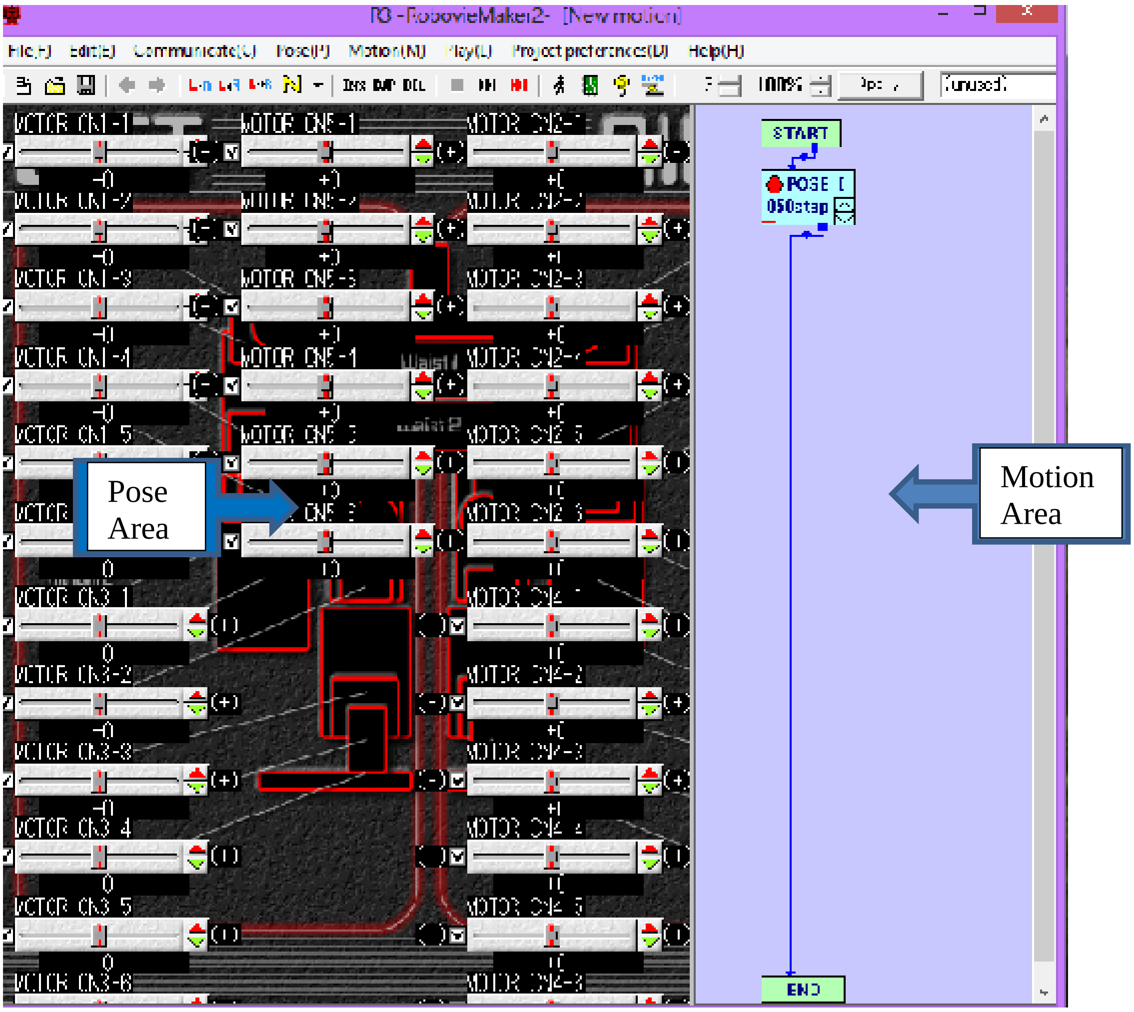

Figure 3.7: RobovieMaker2 software

3.5 Methodology and Observations

Before shaping the interactive games scenarios, a series of user studies are done. The data obtained from the user studies and the observations are mapped this research. Each user study is gave an insight to improve the experimental setup. In the first experiment, we started with 2 signs and 3 upper body movements. Next experiment is done with 8 signs and the following experiment is done with 15 signs and the last user studies are done with 10 signs. The aim of this experiments are to find the optimal number of words in one session that participants can learn the signs without the effect of boredom and fatique. The comparison of robotic platforms is given in Table 3.4.

Table 3.4: Comparison of robotic platforms [96].

Robots		Nao 	R3 
DOF	Wrist	1	1
	Arms	2* arms*4	2* arms*4
	Neck	2	3
	Fingers	2*3 (dependent to each other)	2*5 (independent from each other)
Cameras		2 color cameras	2 color cameras on eyes + ASUS RGB-D camera integrated to chest
Microphones+ Speakers		On the main board	On the main board
Software	Open source software	Lots of open source software	No open source software
	Embedded modules	Face detection, vision recognition and speech recognition modules	No embedded module
Security		It can fall during the tests but it is small and can not hurt participants	It is a big and heavy robot, but it has no legs safely standing on a wheeled base. 6 PSD sensors and additional bumpers to avoid collision.
Mobility		Leg*2	Wheel*2
Appearance		Toy like	Functional
Weight		4.5 kg	35-40 kg
Height		0.57 m	1.08 m

Table 3.4 (continued): Comparison of robotic platforms [96].

Out of Office usage		Can be transferred to schools/nurseries easily, good for experiments in these facilities	Hard to move out of lab/research center, participants need to come to research center
Emotive face		No mouth, eyes with colored lights and head light used for emotions	LED mouth (neutral and smiling face),no other lights on the head
Tactile sensor		On the head, and on hands On the head, and on shoulders	On the head, and on hands On the head, and on shoulders
Work time		Limited work time due to over-heating especially in standing position	Longer work time, over heating is not a problem

3.6 The Framework Overview

We design a complete framework for humanoid robot – children interaction especially for sign language teaching. Because this thesis is a part of ongoing project, not all the parts of the framework is implemented. The designed framework is shown in the Figure 3.8. The green parts of the framework are implemented within the scope of this thesis. In the future, we desire to use electroencephalography device for measuring the child emotion at each step and shape the interaction using this information. We will also use eyes tracker device and range sensors for understanding the child's interest in the future. The implemented part of framework on Nao robot includes face detection for understanding child's interest. On the robot Robovie R3, the face detection module is on progress. We use manual generation module in the field studies. All the other modules will be integrated to the system as future work.

The designed framework components are input modularity, external processing units, recognition module, role module, behaviour selection, behaviour database, robot control module, generation module and output modularity. The input modularity that describes the system inputs including human/children inputs that are electrical activity along the scalp, vision, motion, voice and haptic input. The system also has external inputs that are color flash cards and musical instruments. Electrical activity along the scalp will be obtained from the EEG device and it will be used for participant's emotion detection. The vision of participant can be his/her detected motions by using RGB-D camera or his/her tracked eyes by using eye tracker device.

RGB-D camera will be used for motion detection and eye tracker device will be used for measuring the interest of participants, if the participant loses his/her interest and motivation the robot will motivate the participant. By using these inputs and the external processing units the detection module will be activated, the robot will decide its state by using the emotion detection module and the game will be adaptable to the participant's disability degree or capability of interaction. According to robot's state, robot will select its behavior from behavior database; the robot control module will be active. The participant's emotion and interaction capability will change the robot's mode automatically without human assistance. The mechanism will be adjustable based on the condition; the interaction level of complexity will increase or decrease. We also use the sensors of robots to control and maintain the system. We map the sensor readings to actuators to accelerate the modules. It will be an intelligent control including adaptation.

3.7 The System Overview

The system works in three modes. All the modes can be used separately or together. The first mode is *introduction* to the robot and signs. The second mode is *reinforcement* to the signs. In the second mode, the robot and the participant repeat the signs together. In the third mode, humanoid robot and participant play an *interactive game* using the signs the participant has already learnt. There are 4 types of games in the current system but the system is adaptable to different game scenarios by little modifications. The detailed information about modes will be given in detail.

3.8 First Mode: Introduction to Signs and Robot

The first mode is staged through sign language imitation and visual feedback for teaching the semantics and generation (kinematics) of signs. This mode combines face detection module with the robot control module to handle imitation realization on Nao robot. The mode has multimodality feature that means verbal clues and visual clues can be used together to teach the semantics of words to the participants. The feature of multimodality allows the system usage with participants who have different communication problems such as hearing impairment and autism.

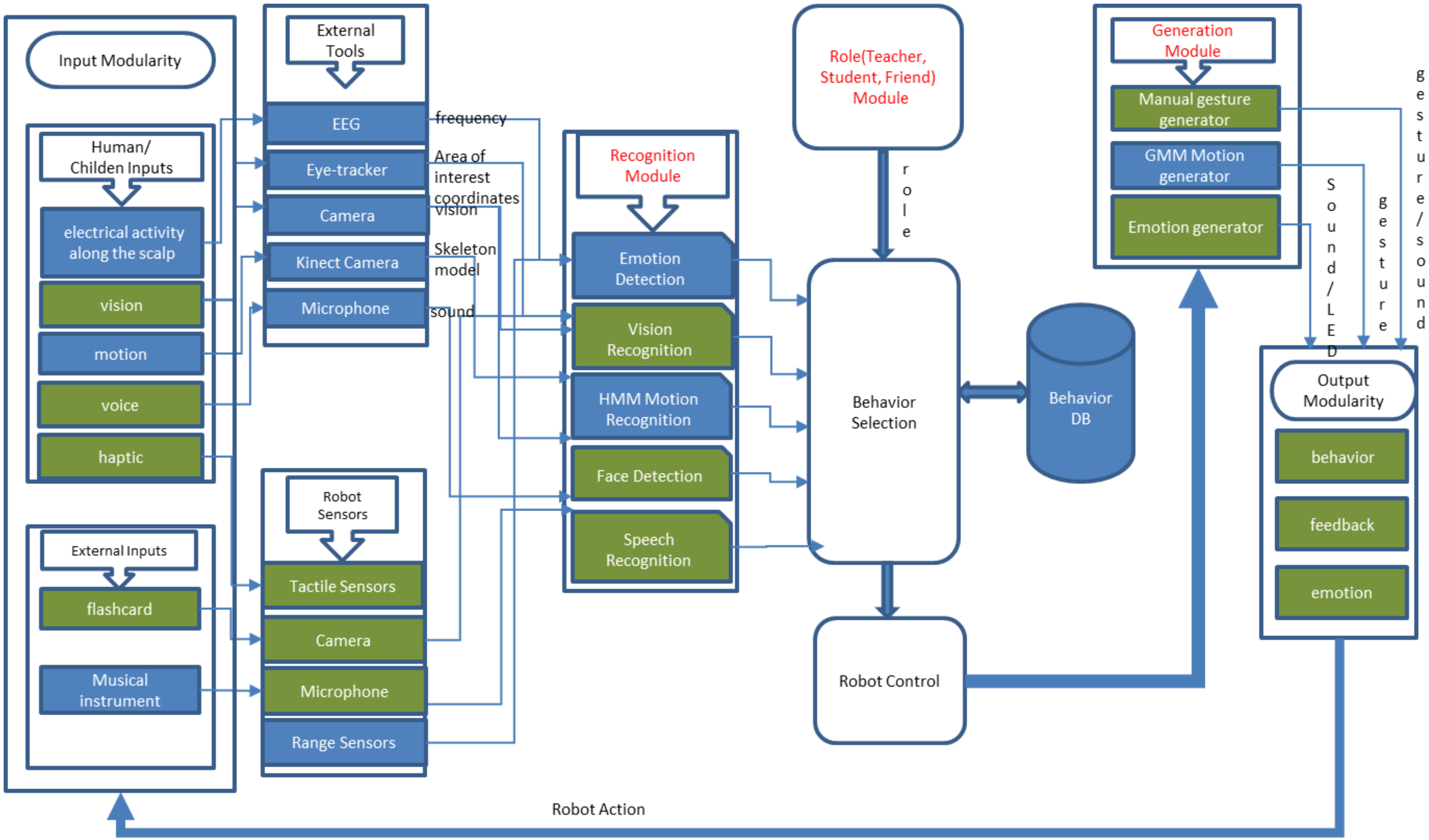

Figure 3.8: Complete framework for humanoid robot – children interaction

It is also possible to use the current system with participants who have no communication problems without any further alterations.

At the beginning of the mode, the experimenter explains the experiment to the participants and conducts the experiment with colored flash cards. She shows colored flash cards to the participants and the robot performs the gesture on the card. In this mode, the robot performs the signs consecutively and says the names of signs at the same time. The aim of using flash cards and verbal clue is to teach the meanings of signs to the participants.

On the system with Nao robot, it detects participant face while teaching signs, if the robot loses the participant's face; the robot stops for a while and waits to detect face. If the robot detects the face again, it resumes to teaching signs. The aim of face detection is to keep participant's interest alive. If the participant is not interested within 30 seconds then the robot gives motivation to the participant by changing eyes LEDs in different colors. If the participant is still uninterested then the robot starts to dance to take the participant interest. In the robot Robovie R3, there is no engagement module in this mode.

In this mode, Aldebaran ALFaceDetection module is used for detecting faces, within this module the event "FaceDetected " is raised each time the robot detects a face. The mode starts with the robot introduction itself, and then the robot informs the participant to interest with it while teaching signs. The experimenter shows corresponding flash cards to the child and child tries to learn both expressions and meanings of signs. In this mode child is passive observer. Table 3.4 shows the roles of participant, experimenter and the robot in this mode. The cycle of sign teaching process is given in the Figure 3.9.

Table 3.5: Roles of robot, participants and experimenter in the first mode.

Peer	**Role**
Robot	Active demonstrator
Participants	Passive observer
Experimenter	Card showing to the participants

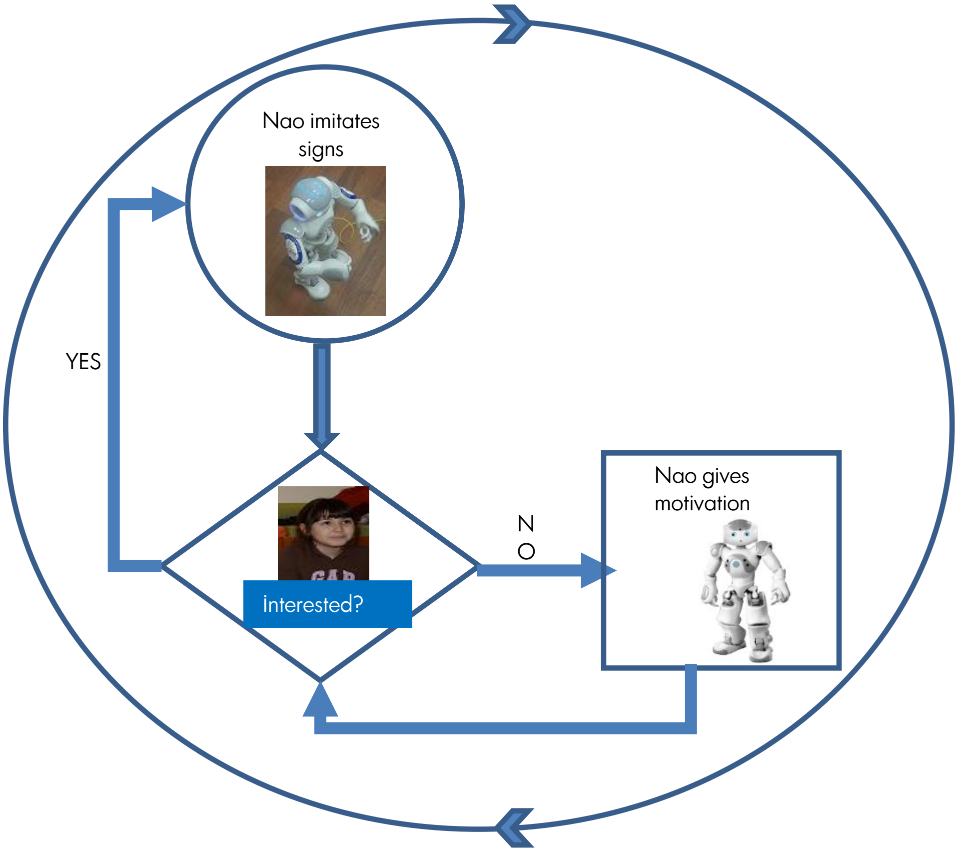

Figure 3.9: Sign teaching cycle.

3.9 Second Mode: Reinforcement of Signs

The second mode is the reinforcement mode. In this mode, the participant and the robot repeat the signs together. The main purpose of this mode is to gain reinforcement of signs to the participant. In this mode, the robot demonstrates the signs autonomously in a pre-defined order. There is still an experimenter to guide the participant and to show the pictures of signs to the participant to reinforce the meanings of signs together with the expressions. In this mode, the participant is active demonstrator. The roles of the participant, experimenter and the robot is given in Table 3.5.

Performing the gestures with the robot aims to progress the participants' kinematic imitation skills and improve the sensory motor coordination.

In this mode, on Nao, Aldebaran ALMotion module and ALBehaviorManager module are used. By using these modules, the signs that are created with Choregraphe timeline boxes can be called from C++ code. The robot expresses one sign, waits 2 seconds, and expresses another. In this mode, there is no face detection.

Table 3.6: Roles of robot, participants and experimenter in the second mode.

Peer	Role
Robot	Demonstrator and Sign Language Tutor
Participants	Active observer and Demonstrator
Experimenter	Card showing to the participants

On the robot Robovie R3, we used remote controller to initiate the movements. The experimenter controls the order of signs. In the complete scenario, the robot will be configured to wait for the participants to perform the signs correctly to continue with new signs by using RGB-D camera. The kinect camera will recognize the participants' expressions and after the correct expression is captured by the camera, the robot will resume to perform a new sign.

3.10 Third Mode: Interactive Games

At the end of the learning process, the participant and the robot play an interactive game using the signs that the participant have already learnt in the previous modes. The aim of this interactive game was the reinforcement of the signs in an enjoyable way. In this mode, participant is informed about the selected game by the experimenter and asked to answer given questions with respect to the game content. The experimenter is still available for answering special questions and for intervening the possible problems.

Four different interactive games implemented. The experimenter selects the type of game by using the tactile sensors of the robot on Nao and the switch is used on R3. In this mode, Nao ALSensors module used for detecting haptic sense, within this module the events such as "FrontTactilTouched", "MiddleTactilTouched" and "RearTactilTouched" raised each time haptic sense detected. For using these events, ALMemory access is required to get the state of tactile sensors. The module can be called locally on the robot. Each tactile initiates a different game.

This mode also includes a vision recognition module. The games are managed by different colored flash cards. The usage of flash cards helps the participant to remember the signs. It is also important for hearing impaired children to involve them into the game. In the card recognition, ALVisionRecognition module is used. The module provides a template matching method to recognize the pictures learned previously. The picture learning process is done with Choregraphe software by using Video Monitor. Each picture is sent to a local database with a user named label. After all pictures are taught to Nao the vision database is sent to the robot. “PictureDetected” event is raised each time a picture detected. Like other local modules, the results are stored in ALMemory. After getting recognized picture from the memory, we can reach picture label by using ALValue. The recognition process is robust to rotation, distance and angles. The key points are used in the recognition so the module cannot recognize untextured objects. The implemented games are detailed as below:

3.10.1 iSpy-Usign game

This game is inspired from the “I spy” game. Depending on the application convenience, the desired tactile sensors can be selected by little code modifications on Nao robot or the switch mode can be selected on R3 robot. This game is fully interactive which includes the child to the game actively. Instead of the child being a passive learner, the experimenter shows a flash card to child and robot in turns (the other cannot see the card), and the child/robot tries to describe the card with sign and the other tries to guess the related word. The signs asked to the child are in a strict order. In the recognition module, Kinect camera will be used and this module is in progress so the signs are needed to be in predefined order. The child should guess the sign correctly for taking turn. In robot’s turn, experimenter shows card to the robot, and robot makes the gesture without any verbal cue. The child is expected to show the related flashcard to the robot (all cards are displayed in front of the child). Robot gives feedback to the child with eyes LEDs and motivation sentences on Nao robot and with mouth LEDs on R3 robot. The robot R3, makes a smile with its mouth LEDs for positive feedback and makes a neutral expression by using its LEDs for negative feedback. If the child guesses the sign correctly Nao’s eyes goes to green color, in the wrong guess Nao’s eyes goes to red color. For feedback mechanism on Nao, ALLEDs module is used. By enabling, the child to take an active role in the game increases the child’s awareness of the words and learning. Child takes the initiative and can take the role “teacher” as well as the role “student”.

The role of robot and the child is given in Table 3.6.

Table 3.7: Roles of robot, participants and experimenter in the game.

Peer	Role
Robot	Peer (student-teacher in turn)
Participants	Peer (student-teacher in turn)
Experimenter	Selects which sign will be asked

3.10.2 Story game

In this game, the robot tells a story using the words the participant have already learnt. In the story, the robot expresses some words signs while saying them. In the card recognition as mentioned above ALVisionRecognition module is used on Nao. Within this context, we expect to observe a positive effect of learning performance.

3.10.3 Sentence game

In this game, the robot expresses a simple sentence with realizing three signs consecutively. The robot waits 5 seconds between two sentences. The participant picks up relevant flash card, which has three pictures on it, corresponds the sentence. If the participant cannot guess the sentence in three attempt then the experimenter helps to the participant and the game continues. The game tries to help participant to improve his/her performance in a comfortable learning environment. In the picture, recognition ALVisionRecognition module is used on Nao. In R3, Wizard-of-Oz method is used, the experimenter controls the robot by using remote controller.

3.10.4 Nonverbal story telling

This game has not been tested yet. In this game, the robot tells a fully nonverbal story by expressing all the words with sign language. The robot tells the story two times. In the first time, it is expected to the participant to understand the story. In the second time, the robot tells the story again but after some words, it waits to see next word’s picture to continue the story. The aim of this context is to reinforce the semantics of signs with an enjoyable way. It is easy to remember the signs by visualizing the words in the memory with a story.

4. EXPERIMENTS AND RESULTS

Due to the incompetency of 2-D instructional tools and the lack of sufficient educational materials in sign language teaching, in this thesis we design new methods to teach and test sign language using humanoid robots and interaction games. The study is progressed systematically, before going forward; some pre-experiments are designed to understand the usefulness and practicability of the idea and test setup. Experiments start with simple design and the complexity of them increases in each step. The main aim of these experiments is to examine how a humanoid robot can encourage learning sign language as an assistive tutor and improve social interaction in children with disabilities especially for hearing impaired and autistic children. Performance evaluation and effectiveness of a humanoid robot as a sign language tutor in advancing social interaction is explored by analyzing the results of experiments. Initial experiments are tested with adults mainly from Istanbul Technical University undergraduate and graduate students, primary school children and kindergarden students. The aim was to figure out the experimental set up improvement before using the system with disabled children. The preliminary results of experiments provide a guideline for more suitable experimental design in establishment of social interaction between a humanoid robot and children. We have applied nine different initial experimental studies. The experiment setups are introduced below. In each experiment, we define participant set and sample, experiment setup and results and discussions.

4.1 Experiment 1: iSpy-Usign Game with Nao Robot

4.1.1 Research questions and hypothesis

In the first experiment, we started with exploring a basic question:

- The effect of using humanoid robots and interaction games to teach sign language from the aspect of participants’ motivation in learning SL.

Our hypothesis was:

- Using humanoid robots as sign language tutors and supporting the learning process with interactive games will motivate the participants in terms of both sign language learning and willingness of interaction with robot.

4.1.2 Participants and sample

The first prototype of the proposed system was tested with 7 undergraduate and graduate students from Computer Engineering Department of Istanbul Technical University (6 males and 1 female) and 5 primary school students (3 girls, 2 boys) with normal development who are attending classical guitar lessons at *Savaş Çekirge Guitar Center* at ITU. The ages of university students are between 25 and 31 and all the children were 8-year-old in the preliminary user study. All the participants in this experiment have no previous knowledge about SL.

In this experiment, we used 6 signs that are 2 basic upper torso movements: up and side, 3 words from TSL that are table, father and car and one word from ASL that is sorry.

4.1.3 Experiment setup

In this experiment, iSpy-Usign game is tested. The experiment has 3 phases. In the first phase, the robot and the pre-selected signs are introduced to the group of children in the class. In this phase, 3-5 children stay around the robot. The robot shows all the signs (currently 6 signs: up, side, table, father, car and sorry) and says the names of the signs verbally as well. This demo is repeated twice. The robot's expressing the sign action is initiated with the teacher's showing the related colored flashcard to the robot. The teacher shows the cards also to the children to let them learn the signs meanings in a multi-modal way.

In the 2nd phase, the robot expresses all the words saying the names in a singing like voice with a rhythm. In this phase, the robot expresses the signs autonomously. The children imitate the robot by expressing the signs together with the robot. In this phase, robot produces a music like sound by expressing the words verbally in a rhythmic way and the children expresses the gestures in a dance like manner. We claim to motivate the children like a musical dancing game rather than just giving the gestures and the words in a simple manner. The order of words in the second phase is same as the demo phase but in this phase, the words are repeated without stopping and waiting for a card. In this manner, we aim to increase the children’s performance in kinematic imitation and sensory-motor coordination. This phase aims to teach the signs vocally and kinematically rather than semantically. A screen shot from the second phase is shown in Figure 4.1.

In the third phase, the robot and each child play one-to-one turn-taking game that helps the child to verify and test the words she/he learned in the first two phases. This part is inspired from the “I spy” game. In this game, the child is not only a passive learner but has the chance to use the words actively she/he learned. The child takes the initiative and teaches signs to the robot, as well, which is expected to increase the child’s motivation and performance in learning and remembering the words. Instead of the child being a passive learner, the teacher shows a sign card to child and robot in turns (the other cannot see the card), and the child/robot tries to describe the sign and the other tries to guess the related word. For instance, if the teacher shows the card “up” to the child, the child expresses the “up” gesture. Then the child shows a “question mark” to the robot. The robot has to say “up”. If the child cannot make the gesture right or the robot cannot recognize the gesture than this action is repeated. The child is motivated to give feedback to the robot with green tick sign (right), and red cross sign (wrong). The case where the child deceives the robot showing the wrong feedback card is not considered within this experiment. Robot shows its “feelings” with colored lights and motivation sentences. In robot’s turn, teacher shows another card to the robot, and robot makes the gesture without any verbal cue. The child is expected to show the related flashcard to the robot (all cards are displayed in front of the child). If the guess is correct, robot says a motivation sentence i.e. “you are the best!” else asks the child to make another guess. For every question the child and the robot can make two “guesses”. Then the teacher gives the right answer, and they start the next question. This multi-modal phase combines the semantics, kinematics and visual features of the words. The aim is to increase the child’s performance and awareness of the words by enabling the child to take an active role in the game and learning. Child takes the initiative and can take the role “teacher” as well as the role “student”.

At the fourth phase, the participants were given paper-based tests, which contain the pictures of signs. The robot expresses every word without verbal cue and the participants are asked to find the related sign and write the matching number. These paper base tests are helpful in the evaluation of participants.

Figure 4.1: A screen shot from experiment 1.

4.1.4 Results

The adults and children were almost 100% successful in the third and fourth phase (1 girl could not remember “table” sign, and got clue from the teacher. 1 boy refused to complete the paper based test, but when he was asked the words later on he could remember them with success). The children showed interest in the game and two weeks after the test, they could still remember the signs successfully. One of the children, who was diagnosed with hyperactivity problems, obeyed all the instructions of the robot and showed success in the game without any warning or help from the teacher.

This experiment results were presented in 22nd International Symposium on Robot and Human Interactive Communication Conference (RO-MAN 2013).

4.1.5 Discussions

However, our essential aim is to test the experimental study with hearing impaired children, we tested the system with hearing participants for gaining insight about the system usability. In this experiment, we noted that learning 6 signs in one session is quite easy for children and adults. We decided to increase number of signs in next sessions with the aim of coming up with optimum number of words in one session.

4.2 Experiment 2: Optimizing the Number of Words

4.2.1 Research questions and hypothesis

In this experiment, the question was:

- How many numbers of words can be learnt in one session?

Our hypothesis was:

- Between 8 and 10 words would be ideal in one session.

4.2.2 Participants and sample

The experiment was tested with 6 primary school students (3 girls, 3 boys) with normal development who are attending classical guitar lessons at *Savaş Çekirge Guitar Center* at ITU and 5 of them also attended the previous experiment.

4.2.3 Experiment setup

In this experiment, Nao H-25 humanoid robot teaches signs. This experiment includes 8 signs in total: 3 of them are from the previous experiment (table, sorry, car) with additional 5 new signs (friend, black, lamp, mountain, mother). The procedure of teaching signs is similar to the previous experiment except the third and fourth phases. In the first phase, the robot introduces the signs. In the second phase, the children and the robot repeat the signs together. In the third phase, the robot expresses the signs with a different order and the children try to guess the signs verbally. Children did not play a game with the robot and they are not given paper-based tests. In this experiment, we only observed the number of words effect.

4.2.4 Results

The children imitated the signs successfully. We asked the signs verbally and they were able to remember all the signs. We did not collect the results from each child but we observed that 8 words in one session is quite ideal even the number can be increased.

4.3 Experiment 3: The Comprehensibility of Signs from The Humanoid Robot Realization with Hearing Impaired Participants

4.3.1 Research questions and hypothesis

The research questions in this experiment was:

- The success of robot in realizing signs,
- The observability of social interaction between a humanoid robot and the hearing impaired participants

4.3.2 Participants and sample

The experiment was tested with 3 adults (30-40 age group) and 1 child (6 year-old). All the participants in this experiment were hearing impaired. One of the adults is sign language teacher who teaches TSL in different universities and courses. The other two adults are parents of the child; the father is fully hearing impaired. The mother uses cochlear implant so she is partial hearing impaired. Including the child, all the participants knows TSL.

4.3.3 Experiment setup

In this experiment, we aimed to learn if the humanoid robots are successful in realizing signs from the hearing-impaired people point of view. 15 words from TSL were shown to the participants on Nao robot and 10 words from TSL on R3 robot is observed by them. One of the participants was asked to show the words and this activity is recorded by Kinect camera for offline evaluation. They claimed that the Nao robot is mostly successful in realizing signs except some signs because of its short limbs and dependent fingers. They were pleased to see a robot implementing their language (TSL). They remarked that R3 robot is more successful in realizing the signs. The child seemed the Nao robot as a toy and she did not take the robot seriously but she perceived the R3 robot as a peer and repeated the signs together with the robot.

4.3.4 Results

After we asked advice hearing impaired people, their claims validated we are on the right way. Their pleasure encouraged us to go forward.

4.4 Experiment 4: Sentence Game with Nao Robot

4.4.1 Research questions and hypothesis

We tried to explore following questions in this experiment:

- Are the learners' competence, performance and interest of learning sign language improved when humanoid robots are used to teach Sign Language (SL)?
- Do the learners enjoy while learning sign language via interaction game with the humanoid robot? Do the interaction games ease the learning process?

4.4.2 Participants and sample

The preliminary tests were performed with fourteen volunteers (7 female, 7 male). All participants were graduate students in Computer Engineering Department of Istanbul Technical University (ITU), Turkey. The ages of the participants were distributed in the range of 24 – 28. None of the participants had any sign language knowledge prior to the experiments.

Selected 15 TSL words were introduced to the participants. The words were baby, to throw, apple, big, black, car, me, my, school, to wait, mother, to get hungry, spring, mountain, to come. In this experiment, Nao humanoid robot is used.

4.4.3 Experiment setup

One of the most important features of this game is that it is suitable for nonverbal communication. Another important feature of this game is that the experiments aim to teach not only expressions of signs but also meanings of signs. The best experimental setup should be adaptive according to the degree of children's disabilities. If the child has a little of hearing (or sound devices i.e. cochlear implant) then using a sound-like child voice and colored flash cards motivate and help the child as a part of speech therapy. If the child has no hearing ability, then the use of colored flash cards would be enough to encourage the child to play with robot without further help or instructions.

In this experiment, Nao is placed almost 1 m away from the participants on the floor (to avoid its falling down accidentally during its actions and hurting anybody). The participant actively takes part in the experiment through interaction games based on non-verbal communication, turn taking and imitation. The play scenarios are designed with different levels of complexity including teaching phases, reinforcement phases and game phases. Game consists of three levels. In the first level, participants introduce with robot and familiarize with signs. In this level, optimally 2-3 participants watch the robot. The robot performs 15 gestures (from Turkish sign language) and says the meanings of signs. The purpose of this level is to teach participants both expressions and the meanings of signs.

In the second level, participants gain reinforcement and recognition with signs by repeating the signs with the robot. The robot waits for participants to perform signs correctly to continue with new signs. Performing gestures aims to progress children kinematic imitation skills and get improvement in sensory motor coordination. In this level rather than teaching words in semantically, teaching them kinematically is the basic goal.

Third level is an interactive game between robot and participant. At the end of the learning process the participant and the robot plays an interactive game using the signs the participant have already learnt. In this level, the humanoid robot and the participant interacts one-to-one. The aim of this interactive game is the reinforcement of the signs with an enjoyable way. In these test, any clue is given to the adult participants. The robot expressed the sentences with three words using sign language and waits for a predefined time period and expressed new sentence. The adult participants write down their guessed sentences and observe new sentence. By using this game, it is aimed to improve the performance in a comfortable learning environment. In the figure 4.2, a screen shot from the experiment is given.

Figure 4.2: An adult participant plays with the robot.

4.4.4 Results

The participants of the experiment are 14 graduate students with similar educational background and without any prior knowledge of sign language.

The recognition rate of signs in this test combined with the test results obtained from the previous studies that are performed with 5-9 years children in *Experiment 1 and Experiment 2* indicate that learning 6 to 8 signs in one session is ideal and learning 15 signs in one session may be confusing for beginners. The TSL words, their English meanings and the recognition rate of signs are displayed in Table 4.1.

Table 4.1: TSL words and recognition rate of participants.

Turkish word	English meaning	Recognition rate of participants
Bebek	Baby	79%
Atmak	to Throw	50%
Elma	Apple	36%
Büyük	Big	100%
Siyah	Black	57%
Araba	Car	100%
Ben	Me	43%
Benim	My	43%
Okul	School	7%
Beklemek	to Wait	36%
Anne	Mother	36%
Acıkmak	to Get hungry	43%
İlkbahar	Spring	71%
Dağ	Mountain	71%
Gelmek	to Come	57%

It is important to notice that apart from similar sign set that are apple, me/my, school, to wait, mother, to get hungry; the recognition rate for the other signs are equal or higher than 50%. The highest score is 100% for 2 signs that are big and car. The higher recognition rates demonstrate that Nao robot was able to teach some of the signs with accuracy and the participants were able to recognize these signs each time they were asked to guess their semantic meaning.

The recognition rate of similar signs are low. The similarity among the signs allows us to explain the low recognition rates. It is important to remark that all the signs with a low recognition rate had another sign performed with a slight difference of the arm or the hand movement. The similar signs with different meanings are shown in Table 4.2.

Table 4.2: Similar signs.

Word	Similar word
Apple	Wait
Me/My	Get Hungry
School	Mother

This experiment results were presented in 2013 IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO 2013) [96].

4.4.5 Discussions

Despite the fact that the higher recognition rate of signs in the previous study with the children encouraged us to use a larger set of signs to teach in this study with the graduate students, the results show that the use of a set composed by 15 signs in one session isn't effective in the teaching of sign language. On the other hand, the low recognition rates relating to the previously specified set of signs indicate that Nao is not capable enough to demonstrate the similar signs and the learning rates for the signs with similar gestures are low. The confusion mostly originates from physical limitations of Nao H-25 robot. Several participants claimed that the robot's small figure and short limbs also made it hard for them to see the gestures in precision, and distinguish similar gestures from each other. In addition, the fact that there are no "head" gestures in this experiment.

4.5 Experiment 5: Word Guessing Game with Robovie R3 Robot

4.5.1 Research questions and hypothesis

The main research questions in this experiment:

- Does the robotic platform with five fingered hands affect the learning performance?
- What is the difference between Nao humanoid robot and Robovie humanoid robot in SL teaching?
- How differ the perception of humans in both robots?

We expect to see that R3 performance is better than Nao. Because R3 has five fingers, it can express signs more precisely, learning SL from R3 is easier than learning SL from Nao. The size of the robot is also effective in teaching SL; R3 is bigger than Nao so humans perceive R3 more seriously.

4.5.2 Participants and sample

The experiment was tested with 21 volunteers. There are 8 female and 10 male participants from Computer Engineering Department of Istanbul Technical University graduate students and 2 female and 1 male teenager participants. The age of adult participants range 21-32 and the teenager participants' ages are 11-14. All the participants are hearing and none of the parcipicants has prior knowledge about SL except from one participant who knows TSL in beginners' level and 3 participants who had an opportunity to get familiar with the language during our previous test studies.

In this experiment, we tested 10 words from TSL. These words are spring, to come, to throw, me, big, mountain, table, black, baby, mother.

4.5.3 Experiment setup

The robot stands still during the tests, the arms of the robot might hit the people who stand in very close proximity. Therefore the adult participants and teenagers are asked to sit to the chairs in front of the robot that are placed 1.5 m away from the robot, and told not to touch the robot during operation.

There are two experimenters in this experiment. One of the experimenters controls the robot and the other experimenter gives feedback to the robot and participants with colored flash cards. For the hearing impaired children the use of flash cards with cartoon like pictures can allow us to communicate with them and to maintain the interactive game. The participants are given pre-test and post-test to collect data about the game design and to evaluate the rate of sign language learning.

The scenarios have no verbal clues, only have visual clues. Computer vision module of the scenario is not completed yet therefore we used Wizard-Of-Oz method. One of the experimenters controlled the pre-coded actions of the robot with its remote control. The game has three phases. The first phase is the introduction to the robot and the signs with similar to Nao robot experiments. This phase starts with the robot introducing itself and the signs. In this phase one of the experimenters explains the experiment to the participants and conducts the experiment with colored flash cards. She shows colored flash cards to the participants and then shows the cards to the robot. Another experimenter activates the gesture on the card with robot's remote control. The aim of using flash cards is to teach the meanings of signs to the participants. In this phase participants are passive observers. The second phase is the reinforcement phase. In this phase participants are active observers, they perform the signs with the robot. The robot demonstrates the gestures autonomously in a pre-defined order. The experimenter shows the cards only to the participants with the aim of reminding them the meanings of signs. In the third phase, participants were asked to answer given questions with respect to the gestures the robot has already performed. The experimenter is still available for answering special questions and for intervening the possible problems. The robot asks the signs with increasing complexity, first part of test includes only one gesture, second part of test includes two consecutive gestures and the last part of test includes three gestures successively. The robot performs the gestures autonomously at a particular time.

The tests are performed with groups of 3 to 4 individuals interacting directly at the same time with the humanoid robot R3. In this study, a set consisting of 10 signs from the Turkish Sign Language is selected in order to evaluate the recognition ability of participants. They were handed a paper-based test in the final level of the interaction game, and they were told to guess the consequent signs performed by the robot and mark the corresponding choice. All the signs were asked at least twice during the test level to give the opportunity and time to remember if the participant couldn't recall the signs.

4.5.4 Results

The recognition rate of all the signs is above than 90% except for one sign, meaning “mother”, with 88% rate of recognition. The success rates of the teenagers are also promising because they are closer in terms of age to our target group. The results indicate that SL teaching can be performed successfully by a humanoid robot. The results indicated that R3 is more accurate and in performing the signs, the recognition rate in the test with R3 is better than the one with Nao H-25 robot within the same word list. The selected words recognition rates displayed in Table 4.3.

Table 4.3: Recognition rate of participants.

Turkish sign	English meaning	Recognition rate of participants with	
		Nao	R3
İlkbahar	Spring	60%	100%
Atmak	to Throw	40%	98%
Ben	I / Me	40%	98%
Büyük	Big	100%	98%
Dağ	Mountain	60%	98%
Masa	Table	-	98%
Siyah	Black	60%	98%
Gelmek	to Come	60%	92%
Bebek	Baby	80%	90%
Anne	Mother	40%	88%

5 test participants participated in both experiments with Nao and R3 advanced their score; they remarked that the movements of R3 are more distinctive and that it was easier to understand the difference between the signs. Regarding the general success rate, there are in total 12 participants out of 21 who have passed the test with a score of 100%, i.e. they could remember and recognize all the signs performed by R3 correctly. The success rates of participants are mostly higher than 89%; the scores vary from 68% to 100%. The success rates of 21 individuals are summarized in Table 4.4. The preliminary results with graduate students and 3 children are encouraging in terms of the humanoid robot’s contribution in the sign language learning process of individuals.

Table 4.4: The summarized success rate of participants.

Gender	Number of Participants	Success Rate of Participants
F	10	94%
M	11	98 %
Total:	21	**96%**

These results show that the presented interaction game can be played with children who have different degrees of hearing disability and the humanoid robots may be presented as an effective teaching material in the context of improving the interaction ability of the children. Learning with the assistance of a humanoid robot increases motivation and ease the learning process. After one week from experiments, the participants can still recall the signs. We have gained insight into the effectiveness of humanoid robot for teaching sign language and design of experiment setup how participants can interact comfortably with the robot. The parameters of the game will be adaptive to optimize the learning process for individual participants, in the future.
The results of this experiment is presented on IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2013) [94].

5. CONCLUSIONS AND FUTURE WORK

This thesis set out to investigating the role that humanoid robots play in various aspects of social interaction establishment using sign language. In this chapter, we will review the research contributions of this thesis as well as discussing the future work.

Most assistive robotics research focuses on using robots as therapy tools for helping the children with communication problems especially ASD. In this thesis, we proposed a robotic solution for improving the social interaction of the hearing impaired children. Our approach to teach sign language is to give words within interaction games to encourage the children social establishment with humanoid robots easily. We examined the words in TSL dictionary and selected the words in terms of Nao H-25 humanoid robot physical limitations. We implemented the words on Nao robot. We have observed the impact of humanoid robots in teaching sign languages by performing a series of user studies. Our initial results reveal that the perception of humanoid robots as a sign language tutoring assistant is quite promising. In the interaction games, we both used verbal and visual feedbacks to teach semantics of signs. To the best of our knowledge, there is no previous study that reports the usage of humanoid robots for helping teach sign language to hearing impaired children in the literature. The proposed system aims to compensate this mentioned lack while being supportive to hearing impaired children.

This thesis has been carried out as part of an ongoing research, with the aim of helping to teach sign language to hearing impaired children by generating interaction based games between a humanoid robot and children. We design a complete framework that cares the child motivation and interest during the teaching sessions. Part of this framework is implemented within the scope of this thesis.

In this study, we used face detection to understand the interest of participants during the teaching phases. We also tried to optimize the number of words can be learnt in one session by user studies. A proper assessment of a sign language tutoring assistance scenario requires monitoring the hearing impaired children over long periods of interaction.

The following are main research contributions of this thesis:

- a framework design that is suitable for humanoid robots and children complete interaction using sign language.
- implementation of selected words from TSL by using humanoid robot Nao H-25 (100 words), and Robovie R3 (13 words).
- interaction game design that can be used between humanoid robots and children.

5.1 Future Work

There is an ongoing study to move the whole project to Robovie R3 humanoid robot since it is a robotic platform with five fingered hands to prevent the similarity of the signs and emphasize the importance of the finger gestures. In addition, the rest of the framework, which is not implemented within this thesis, will be covered as future work such as introducing eye- trackers to the system to verify the interest of attendees. Also the studies will be tested with hearing impaired children in the long term experiments.

REFERENCES

[1] Goodrich, M. A., and Schultz, A. C. (2007). Human-Robot Interaction: A Survey. Foundations and Trends in Human-Computer Interaction. 1(3), pp 203-275.

[2] Watanabe, T., Okubo, M., Ogawa, H., (2000). A speech driven embodied interaction robots system for human communication support. Systems, Man, and Cybernetics, 2000 IEEE International Conference on, vol.2, no., pp.852-857 vol.2.

[3] Andrist, S., Spannan, E., and Mutlu, B., (2013). Rhetorical Robots: Making Robots More Effective Speakers Using Linguistic Cues of Expertise. In *Proceedings of the 8th ACM/IEEE Conference on Human-Robot Interaction (HRI 2013),* Tokyo, Japan.

[4] Kubota, N., and Kojima, H., (2006). An Utterance System of a Partner Robot Based on Interaction and Perception. *Automation Congress. WAC '06. World* , vol., no., pp.1-6.

[5] Kanda, T., Ishiguro, H., Ono, T., Imai, M., Mase, K., (2002). Multi-robot cooperation for human-robot communication. *11th IEEE International Workshop on Robot and Human Interactive Communication, 2002. Proceedings.*, vol., no., pp.271-276.

[6] Gouaillier, D., Hugel, V., Blazevic, P., Kilner, C., Monceaux, J., Lafourcade, P., Marnier, B., Serre, J., Maisonnier, B., (2009). Mechatronic design of NAO humanoid. *ICRA '09. IEEE International Conference on Robotics and Automation*, vol., no., pp.769-774.

[7] Salichs, M. A., Barber, R., Khamis, A. M., Malfaz, M., Gorostiza, J. F., Pacheco, R., Rivas, R., Corrales, A., Delgado, E., Garcia, D., (2006). Maggie: A Robotic Platform for Human-Robot Social Interaction. *IEEE Conference on Robotics, Automation and Mechatronics,* vol., no., pp.1-7.

[8] Tsagarakis, N. G., Sinclair, M., Becchi, F., Metta, G., Sandini, G., Caldwell, D.G., (2006). Lower Body Design of the `iCub' a Human-baby like Crawling Robot. *6th IEEE-RAS International Conference on Humanoid Robots*, vol., no., pp.450-455.

[9] Nishiwaki, K., Sugihara, T., Kagami, S., Kanehiro, F., Inaba, M., Inoue, H., (2000). Design and development of research platform for perception-action integration in humanoid robot: H6. *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2000) Proceedings*, vol.3, no., pp.1559-1564.

[10] Kaneko, K., Kanehiro, F., Kajita, S., Yokoyama, K., Akachi, K., Kawasaki, T., Ota, S., Isozumi, T., (2002). Design of prototype humanoid robotics platform for HRP. *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2002)*, vol.3, no., pp.2431-2436.

[11] Hackle, M., Schwope, S., Fritsch, J., Wrede, B., Sagerer, G., (2005). Humanoid robot platform suitable for studying embodied interaction.

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), vol., no., pp.2443-2448.

[12] Sakagami, Y., Watanabe, R., Aoyama, C., Matsunaga, S., Higaki, N., Fujimura, K., (2002). The intelligent ASIMO: system overview and integration. *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2002)*, vol.3, no., pp.2478-2483.

[13] Url-1<*http://www.ctc.ca.gov/credentials/creds/federal-disability-definitions.pdf*>, accessed at 3.9.2013.

[14] Spitzer, S., L., (2008). Play in children with autism: Structure and experience. In L. D. Parham and L. S. Fazio (Eds.), Play in Occupational Therapy for Children (2nd ed.) St. Louis, MO: Mosby Elsevier, pp.351-374.

[15] Iacono, I., Lehmann, H., Marti, P., Robins, B., Dautenhahn, K., (2011). Robots as social mediators for children with Autism - A preliminary analysis comparing two different robotic platforms. *IEEE International Conference on Development and Learning (ICDL 2011),* vol.2, no., pp.1-6.

[16] WHO, (2001). International Classification of Functioning. Disability and Health. Geneva: World Health Organization.

[17] Hyun E., S. Kim, S. Jang, and S. Park, (2008). Comparative study of effects of language instruction program using intelligence robot and multimedia on linguistic ability of young children. *17th IEEE International Symposium on Robot and Human Interactive Communication, (RO-MAN 2008),* vol., no., pp.187-192.

[18] Kose, H., Yorganci R., Algan H. E., and Syrdal D. S., (2012). Evaluation of the Robot Assisted Sign Language Tutoring using video-based studies. International Journal of Social Robotics, Special issue on Measuring Human-Robot Interaction, DOI: 10.1007/s12369-012-0142-2.

[19] Kose, H., and Yorganci, R., (2011). Tale of a robot: Humanoid Robot Assisted Sign Language Tutoring. *11th IEEE-RAS International Conference on Humanoid Robots (HUMANOIDS 2011),* vol., no., pp.105-111.

[20] Akalin, N., Uluer, P., and Kose, H., (2013). iSpy-uSign: Humanoid Assisted Interactive Sign Language Tutoring Games. 22nd International Symposium on Robot and Human Interactive Communication Conference (RO-MAN 2013), vol., no., pp.290-291.

[21] Zeshan U., (2003). Aspects of Turkish Sign Language. Sign Language & Linguistics 6:1, pp. 43–75.

[22] Miles, M., (2000). Signing in the Seraglio: mutes, dwarfs and jesters at the Otoman Court 1500-1700. Disability & Society 15: 1, pp. 115-134.

[23] Albertus B., (2002). Albertus Bobovius ya da Ali Ufki Bey'in Anıları: Topkapı Sarayı'nda Yaşam. Çev. A. Berktay, Kitap Yay.

[24] Aran, O., Ari, I., Akarun, L., Sankur, B., Benoit, A., Caplier, A., Campr, P., Carrillo, A., and Fanard, F., (2009). Signtutor: An interactive system for sign language tutoring. IEEE MultiMedia, vol. 16, no. 1, pp. 81-93. Doi: 10.1109/MMUL.2009.17.

[25] Mehdi, S. A., Khan, Y. N., (2002). Sign language recognition using sensor gloves. *Proceedings of the 9th International Conference on Neural Information Processing (ICONIP 2002)*, vol.5, no., pp.2204-2206.

[26] Safisbury, J. K., (1984). Design and Control of an Articulated Hand. *Int* 1. *Symp. on Design and Synthesis*, Tokyo, Japan, 1984.

[27] Sugiuchi, H., Morino, T., Terauchi, M., (2002). Execution and description of dexterous hand task by using multi-finger dual robot hand system - realization of Japanese sign language. *IEEE International Symposium on Intelligent Control*, vol., no., pp.544-548.

[28] Mutlu, B., Osman, S., Forlizzi, J., Hodgins J., and Kiesler, S., (2006). Task Structure and User Attributes as Elements of Human-Robot Interaction Design. *15th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 2006)*, vol., no., pp.74-79.

[29] Nass, C., Moon, Y., Fogg, B. J., Reeves, B., (1995). Can computer personalities be human personalities? *International Journal of Human-Computer Studies*, vol. 43, pp. 223-239.

[30] Morasso, P., Casadio, M., Giannoni, P., Masia, L., Sanguineti, V., Squeri, V., Vergaro, E., (2009). Desirable features of a "humanoid" robot-therapist. *IEEE International Conference on Engineering in Medicine and Biology Society* , vol., no., pp.2418-2421.

[31] Fuji, S., Date, M., Nagai, Y., Yasuhara, Y., Tanioka, T., Ren, F., (2011). Research on the possibility of humanoid robots to assist in medical activities in nursing homes and convalescent wards. *7th International Conference on Natural Language Processing and Knowledge Engineering (NLP-KE 2011)*, vol., no., pp.459-463.

[32] Ismail, L., Shamsuddin, S., Yussof, H., Hashim, H., Bahari, S., Jaafar, A., Zahari, I., (2011). Face detection technique of Humanoid Robot NAO for application in robotic assistive therapy. *IEEE International Conference on Control System, Computing and Engineering (ICCSCE 2011)*, vol., no., pp.517-521.

[33] Dickstein-Fischer, L., Alexander, E., Xiaoan Y., Hao S., Harrington, K., Fischer, G.S., (2011). An affordable compact humanoid robot for autism spectrum disorder interventions in children. *IEEE International Conference on Engineering in Medicine and Biology Society (EMBC 2011)* , vol., no., pp.5319-5322.

[34] Riener, R., (2005). Control of Robots for Rehabilitation. *IEEE International Conference on Computer as a Tool (EUROCON 2005)*, vol.1, no., pp.33-36.

[35] Haberdar, H., and Albayrak, S., (2005). Real Time Isolated Turkish Sign Language Recognition from Video Using Hidden Markov Models with Global Features. *Conferance on Computer and Information Sciences (ISCIS 2005)*, pp 677-687.

[36] Kadous, W., (1995). GRASP: Recognition of Australian Sign Language Using Instrumented Gloves. MSc. Thesis, University of New South Wales.

[37] Starner, T., Weaver, J., and Pentland, A., (1998). Real-time American sign language recognition using desk and wearable computer based video. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 20 , issue 12, pp 1371 – 1375.

[38] Braffort, A., Bolot, L., and Segouat, **J.,** (2011). Virtual Signer Coarticulation in Octapus, a Sign Language Generation Platform. *GW 2011: The 9th International Gesture Workshop; Gesture in Embodied Communication and Human-Computer Interaction*, May 25-27, 2011, Athens, Greece.

[39] Aran, O., and Akarun, L., (2010). A Multi-class Classification Strategy for Fisher Scores: Application to Signer Independent Sign Language Recognition. *Pattern Recognition*, vol. 43, no. 5, pp. 1717-1992.

[40] Keskin, C. and Akarun, L., (2009). Input-output HMM based 3D hand gesture recognition and spotting for generic application. Pattern Recognition Letters, vol. 30, no. 12, pp. 1086 -1095.

[41] Caplier, A., Stillittano, S., Aran, O., Akarun, L., Bailly, G., Beautemps, D., Aboutabit, N., and Burger, T., (2007). Image and video for hearing impaired people. EURASIP Journal on Image and Video Processing, Special Issue on Image and Video Processing for Disability.

[42] Ding, L. and Martinez, A. M., (2009). Modelling and Recognition of the Linguistic Components in American Sign Language. Image and Vision Computing, vol. 27, issue 12, pp.1826-1844.

[43] Zaki, M. M., and Shaheen, S. I., (2011). Sign Language Recognition Using a Combination of New Vision Based Features. Pattern Recognition Letters, vol. 32, issue 4, pp. 572-577.

[44] Suk, H., Sin, B., Lee, S., (2010). Hand Gesture Recognition Based on Dynamic Bayesian Network Framework. Pattern Recognition, vol. 43, issue 9, pp. 3059-3072.

[45] Nguyen, T. D., and Ranganath, S., (2012). Facial Expressions in American Sign Language: Tracking and Recognition. Pattern Recognition, vol. 45, issue 5, pp. 1877-1891.

[46] Paulraj, M. P., Yaacob, S., Azalan, M. S. Z., Palaniappan, R., (2011). A phoneme based sign language recognition system using 2D moment invariant interleaving feature and Neural Network. IEEE Student Conference on Research and Development (SCOReD 2011) , vol., no., pp.111-116.

[47] Gibet, S., (2011). Analysis and Synthesis of Sign Language Gestures: From Meaning to Movement Production. GW 2011: The 9th International Gesture Workshop; Gesture in Embodied Communication and Human-Computer Interaction, Athens, Greece.

[48] Luis-Pérez, F. E., Trujillo-Romero, F., and Martínez-Velazco, W., (2011). Control of a Service Robot Using the Mexican Sign Language.

Advances in Soft Computing Lecture Notes in Computer Science, vol. 7095, pp 419-430.

[49] Anastasiou, D., (2011). Gestures in assisted living environments. GW 2011: The 9th International Gesture Workshop; Gesture in Embodied Communication and Human-Computer Interaction. Athens, Greece.

[50] Ohene-Djan, J., Naqvi, S., (2005). An adaptive WWW-based system to teach British sign language. *ICALT 5. Fifth IEEE International Conference on Advanced Learning Technologies*, vol., no., pp.127-129.

[51] Jemni, M., Elghoul, O., (2008). Using ICT to Teach Sign Language. *ICALT '08. Eighth IEEE International Conference on Advanced Learning Technologies*, vol., no., pp.995-996.

[52] Xu, X., Wang, X., Yao, L., Zhang D., Zhao, **H.,** (2008). Avatars based Chinese Sign Language Synthesis System. *IEEE International Conference on Systems, Man and Cybernetics*, vol., no., pp.444-449.

[53] Ho-Sub Y., Su-Young C., (2006). Visual Processing of Rock, Scissors, Paper Game for Human Robot Interaction. *SICE-ICASE, International Joint Conference*, vol., no., pp.326-329.

[54] Chao, C., Lee J., Begum, M., Thomaz, A., L., (2011). Simon plays Simon says: The timing of turn taking in an imitation game. *IEEE International Workshop on Robot and Human Communication (ROMAN2006)*, vol., no., pp.235-240.

[55] Liu, C., Conn, K., Sarkar, N., Stone, W., (2008). Online Affect Detection and Robot Behavior Adaptation for Intervention of Children With Autism. *IEEE Transactions on Robotics*, vol.24, no.4, pp.883-896.

[56] Adamo-Villani, N., Doublestein, J., Martin, Z., (2004). The MathSigner: an interactive learning tool for American Sign Language. *Eighth International Conference on Information Visualisation*, vol., no., pp.713-716.

[57] Kanda, T., Hirano, T., Eaton, D., and Ishiguro, H., (2004). Interactive robots as social partners and peer tutors for children: a field trial. Human Computer Interaction journal, *19, 61-84*. Doi=10.1207/s15327051hci1901&2_4.

[58] Clark, H. H., (1996). Using language. Cambridge, England: Cambridge University Press.

[59] Hall, E. (1996). The hidden dimension. New York: Anchor.

[60] Dautenhahn, K. and Werry, I., (2002). A quantitative technique for analyzing robot-human interactions. *Proceedings of the IEEE/RSJ International Conferance on Intelligent Robots and Systems*, vol.2, no., pp.113-1138.

[61] Nalin, M., Baroni, I., Kruijff-Korbayova, I., Canamero, L., Lewis, M., Beck, A., Cuayahuitl, H., Sanna, A., (2012). Children's adaptation in multi-session interaction with a humanoid robot. *IEEE International Workshop on Robot and Human Communication (ROMAN2012)*, vol., no., pp.351-357.

[62] Yusufoff, Y., (2009). Baby Sign Language. Bebek University.

[63] Lyon C., Nehaniv C., L., Saunders, J., (2012) Interactive Language Learning by Robots: The Transition from Babbling to Word Forms. *PLoS ONE* 7(6): e38236. doi:10.1371/journal.pone.0038236

[64] Vihman, M., (1996). Phonological Development: the Origins of Language in the Child. Blackwell.

[65] Hickok, G., P., (2004). Dorsal and ventral streams: a framework for understanding aspects of the functional anatomy of language. Cognition 92: 67–99.

[66] Saur D., Kreher B.,W., Schnell S., Kummerer, D., Kellmeyer, P., (2008). Ventral and dorsal pathways for language. *Proceedings of the National Academy of Sciences* 105: 18035–18040.

[67] Kilicaslan, Y., Ucar, O., Ucar, E., Guner, E., S., (2008). Visualization of Turkish for autistic and mentally retarded children. *Second International Conference on Pervasive Computing Technologies for Healthcare*, vol., no., pp.144-147.

[68] Koizumi S., Kanda, T., Masahiro, S., Ishiguro, H., and Hagita, N., Preliminary Field Trial for Teleoperated Communication Robots. *IEEE International Workshop on Robot and Human Communication (ROMAN2006)*, vol., no., pp.145-150.

[69] Ertugrul, B.S., Kivrak, H., Daglarli, E., Kulaglic, A., Tekelioglu, A., Kavak, S., Ozkul, A., Yorgancı, R., Kose, H., (2012). iSign: Interaction Games for Humanoid Assisted Sign Language Tutoring. *International Workshop on Human-Agent Interaction (iHAI 2012)*.

[70] Ertugrul, B.S., Gurpinar, C., Kivrak, H., Kulaglic, A., Kose H., (2013). Gesture Recognition for Humanoid Assisted Interactive Sign Language Tutoring. *The Sixth International Conference on Advances in Computer-Human Interactions (ACHI 2013)*.

[71] Kivrak, H., Ertugrul, B., S., Yorgancı, R., Daglarli, E., Kulaglic, A., Kose, H., (2012). Humanoid Assisted Sign Language Tutoring. *5th Workshop on Human-Friendly Robotics (HFR 2012).*

[72] Kose, H., Yorganci, R., and Itauma, I., I., (2011). Robot Assisted Interactive Sign Language Tutoring Game. IEEE International Conference on Robotics and Biomimetics (ROBIO 2011), vol., no., pp.2247-2248.

[73] Kose, H., Yorganci, R., and Algan, H., E., (2011). Evaluation of the Robot Sign Language Tutor using video-based studies. *Proceedings of 5th European Conference on Mobile Robots (ECMR11)*, pp. 109-114.

[74] Robins, B., (2005). A Humanoid Robot as Assistive Technology for Encouraging Social Interaction Skills in Children with Autism. PhD Thesis, Department of Computer Science, University of Hertfordshire, United Kingdom.

[75] Brim-Jr., O. G., (1966). Socialization through the life cycle, in O. Brim-Jr. And S. Wheeler (eds), Socialization after Childhood, Wiley, New York.

[76] Cohen, S., (1976). Social and Personality Development in Childhood, Macmillan Publishing Company, New York and London.

[77] Vygotsky, L. (1978). Mind in Society, Harvard University Press, Cambridge MA.

[78] Lave, J. and Wenger, E., (1991) Situated Learning: Legitimate Peripheral Participation, Cambridge University Press, Cambridge UK.

[79] Url-2 <http://www.theschoolsadvertiser.co.uk/downloads/Deaf%20Children%20S10.pdf>

[80] Allen, T. E. (1989). Patterns of academic achievement among hearing impaired students: 1974 and 1983. In Schildroth A, Karchmer M (Eds), Deaf Children in America. San Diego: College Hill Press, pp. 161–206.

[81] Mayberry, R. I. (2002). Handbook of Neuropsychology, 2nd Edition, Vol. 8, Part II, S.J. Segalowitz and I. Rapin (Eds), Elsevier Science, pp. 71-107.

[82] **Geers, A.E., and Moog, J. S.** (1987). Predicting spoken language acquisition of profoundly hearing-impaired children. Journal of Speech and Hearing Disorders: 52; 84–94.

[83] Dautenhahn, K. and Nehaniv, C. (2002). Imitation in Animal and Artifacts, MIT Press, Cambridge, MA.

[84] Dautenhahn, K. and Werry, I. (2004). Towards interactive robots in autism therapy: Background, motivation and challenges, Pragmatics and Cognition 12(1), 1–35.

[85] Nadel, J., Gu´erini, C., Pez´e, A. and Rivet, C. (1999). The evolving nature of imitation as a format of communication, in J. Nadel and G. Butterworth (eds), Imitation in Infancy, Cambridge University Press, pp. 209–234.

[86] Bruner, J. S. (1990). Acts of Meaning, Harvard University Press, Cambridge, MA.

[87] Powell, S. (2000). Helping Children with Autism to Learn, David Fulton Publishers, London UK.

[88] Hakkarainen, P. (2003). Play and motivation, in Y. Engestrm, R. Meittinen and R. Punamaki (eds), Perspectives on Activity Theory, Cambridge University Press, Cambridge, UK.

[89] Pot, E., Monceaux, J., Gelin, R., Maisonnier, B. (2009). Choregraphe: a graphical tool for humanoid robot programming. *The 18th IEEE International Symposium on Robot and Human Interactive Communication (ROMAN 2009)*, vol., no., pp.46-51.

[90] Url-3 <*www.aldebaran-robotics.com*>

[91] Url-3 < *http://www.tdk.gov.tr/index.php?option=com_content&id=264*>

[92] RobovieMaker2 User Guide, ATR.

[93] Akalin, N., Uluer, P., Kose, H., Ince, G. (2013). Humanoid Robots Communicating with Participants Using Sign Language: An

Interaction Based Sign Language Game. 2013 IEEE Workshop on Advanced Robotics and its Social Impacts, Tokyo, Japan.

[94] Uluer, P., Akalin N., Kose, H., Yorganci, R., Ince, G. (2013). A New Robotic Platform as Sign Language Tutor. IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, Japan.

[95] 5 Finger hand and Wrist Upgrade User Guide, ATR.

[96] Kose, H., Akalin, N., Uluer, P., Yorganci, R. (2013). Socially Interactive Robotic Platforms as Sign Language Tutors. International Journal of Humanoids (IJHR). (accepted)

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PUBLICATIONS/PRESENTATIONS ON THE THESIS

- Kose, H., **Akalin, N.**, Uluer, P., Yorganci, R., (2013). Socially Interactive Robotic Platforms as Sign Language Tutors. International Journal of Humanoids (IJHR). (accepted)
- **Akalin, N**., Uluer, P., and Kose, H., (2013). iSpy-uSign: Humanoid Assisted Interactive Sign Language Tutoring Games. 22nd International Symposium on Robot and Human Interactive Communication Conference (RO-MAN 2013), vol., no., pp.290-291.
- **Akalin, N.,** Kose, H., (2013). Humanoid Robots Communicating with Children Using Sign Language. The 2013 World Congress on Advances in Nano, Biomechanics, Robotics, and Energy Research (ANBRE13), Seoul, Korea.
- **Akalin, N.,** Uluer, P., Kose, H., Ince, G., (2013). Humanoid Robots Communicating with Participants Using Sign Language: An Interaction Based Sign Language Game. 2013 IEEE Workshop on Advanced Robotics and its Social Impacts, Tokyo, Japan.
- Uluer, P., **Akalin N.,** Kose, H., Yorganci, R., Ince, G., (2013). A New Robotic Platform as Sign Language Tutor. IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, Japan.