ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

THE STUDY OF EMBODIMENT ON HUMANOID ROBOTS FOR TURKISH SIGN LANGUAGE

M.Sc. THESIS

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Department of Computer Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

TÜRK İŞARET DİLİ İÇİN İNSANSI ROBOTLAR ÜZERİNDE VÜCUTLANDIRMA ÇALIŞMALARI

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To my family and friends

FOREWORD

I would like to give my special thanks to my super advisor, Assoc. Prof. Hatice Köse for her great help during the my university life and thesis. Her wisdom and experience guided me to complete this study.

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May 2015

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(Computer Engineer)

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ABBREVIATIONS

API	: Application Programming Interface
ASD	: Autism Spectrum Disorder
DOF	: Degree of Freedom
GUI	: Graphical User Interface
IP	: Internet Protocol
LfD	: Learning from Demonstration
ODE	: Open Dynamic Engine
OS	: Operating System
RM2	: RobovieMaker2
ROS	: Robot Operating System
SDF	: Simulator Description Format
TCP	: Transmission Control Protocol
TSL	: Turkish Sign Language
YARP	: Yet Another Robot Platform

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SUMMARY

Visualizing real world in computer simulations has an essential role in analysing the complex situations. Working with physical devices can be hard and expensive because of unwilling damages and costs. Simulating cases and actions improve the success of projects. Especially in robotic projects, simulators have vital role to prevent accidental damages. Simulators also provide low cost training environments, so more people can study on it. Humanoid robots are widely used in education area and also for therapy of autism. Researcher try to find a common ground to communicate with hearing impaired people and people who have autism. Sign Language provide a common layer for people who can not speak verbally.

This work is part of an ongoing project which aims to actuate humanoid robots as sign language tutoring assistance. Main goal of the project is to help children with communication problems, particularly children with Autistic Spectrum Disorder and hearing impaired children. Our Humanoid robot Robovie R3 does not have a 3D simulator, so this study mainly focus on creating a 3D simulator for our robot and examining success of it on performed sign language words.

There are lots of developed physic engines and simulation environments to visualize projects in computers. Gazebo simulator is an open source improved one and provides many futures. Modelling actions in simulators and transferring them safely to physical world increase success and decrease actual time in projects. Benefits of simulators and necessity of creating Robovie R3 simulator motivate us to develop a simulator on Gazebo environment. It is capable of moving arms and head which is basically enough to sign TSL (Turkish Sign Language) words.

In this study, two sub projects are developed. First one is Robovie R3 simulator on Gazebo environment. It can create motion files and convert them to transfer physical robot. TSL words are performed and saved as motion files on Robovie R3 simulator. In this way both a virtually embodied 3D R3 robot can be created, and also its actions can be transferred to a physical embodied R3 robot. Other project is an android based application, which provide a survey and test environment to examine the quality of showed signs on Robots and simulator and by that means, can serve as a tool to compare and test the effects of different embodiments of the humanoid robots in sign language tutoring. It can be modified to collect data in other projects.

The overall scenario includes three experiment modes. In first mode, TSL words are created in Roboive R3 simulator and played in 3D environment. Collisions on signs are seen and they are fixed to protect physical robot. Performed TSL words are saved as motion files. In second mode, saved files converted to Roboviemaker2 format which is proper to play on physical robot. Than these signs transferred to physical Robovie R3 robot and analysed to measure the success of Robovie R3 simulator. In last mode,

performed signs are recorded on simulator environment and added to android based game environment. This game is played by hearing impaired primary school students which have advanced sign language skills. They solved the sign test and results are quite promising and motivate us for future studies.

TÜRK İŞARET DİLİ İÇİN İNSANSI ROBOTLAR ÜZERİNDE VÜCUTLANDIRMA ÇALIŞMALARI

ÖZET

Bilgisayar simulasyonları gerçek dünyada olan olayları modellemek ve görselleştirmek amacıyla sıkça kullanılmaktadır. Deprem, yangın, savaş gibi felaket senaryolarının sanal ortamda olası sonuçlarını gelişen teknoloji ile görselleştimek mümkün olmaktadır. Bu tip olayların gerçek dünyada tekrarlanmaları mümkün olmadığından simulasyon ortamında gözlemleyerek gerekli önlemlerin alınması gerekmektedir. Bu senaryoların dışında simulasyon programları robotik çalışmalarında da kullanılmaktadır. Günümüzde robotik cihazların çok pahalı olması, bu cihazlarda oluşabilecek istenmeyen kazaları önlemeyi de önemli hale getirmektedir. Aynı zamanda simulasyon ortamları robottan bağımsız olarak birden fazla kişinin aynı ya da farklı projelerde gerekli çalışmaları daha kolay bir şekilde yapabilmelerine de olanak sağlar.

İşitme engelli insanlar ile anlaşabilmek için işaret dili ortak bir alan oluşturmaktadır. İşaret dili el, kol, yüz ve baş hareketlerinin birleşiminden oluşan görsel bir dildir. Sözlü olarak iletişim kuramayan insanlar için doğal bir iletişim aracıdır. Otizmli ya da işitme engelli insanlarla iletişim kurabilmek için kullanılan işaret dili eğitiminde günümüzde insansı robotlardan da yararlanılmaktadır. İşaret dili görsel bir dil olduğundan bu alanda kullanılan insansı robotlarda hareketleri gerçeklemeden önce simulasyon ortamında gerçeklemeyi de önemli hale getirmektedir. İşaret dili hareketleri sırasında insanlar el, kol,yüz ve baş hareketlerini çokca kullanmaktadır. Bu hareketlerin robota aktarılmadan önce 3 boyutlu bir simulasyon ortamında gözlenmesi, fiziksel robotun hareketleri gerçeklerken kollarının vücuduna ya da birbirine çarpmasını önlemek için gereklidir.

İşaret dili eğitiminde kullanılan araç sayısı azdır. Bu çalışma "İşaret Dili Gerçekleme" Tubitak projesinin bir parçası olarak, çalışmada kullanılan Robovie R3 robotuna simulator kazandırmak ve bu sayede işaretlerin gerçeklenmesini ve robota aktarılmasını kolaylaştırmak amaçlanmaktadır. Çalışmada simulatörün işaret dili hareketlerini gerçekleme başarısı gözlemlenmiş ayrıca bu hareketlerin videoları kaydedilerek mobil bir oyun ortamında işaret dili bilen işitme engelli çocuklara oynatılarak test edilmiştir. Simulatörün hareketleri gerçekleme kalitesi bu sayede test edilmiştir.

Robotları sanal ortamda simüle etmek için geliştirilmiş birçok fizik motoru ve simülasyon ortamı bulunmaktadır. Bu ortamlar incelenerek içlerinden açık kaynak kodlu Gazebo simulatorü bu çalışmada kullanılmak üzere seçilmiştir. Gazebo simulator ortamı, fizik motoru ve açık kaynak kodlu bir çok model içermektedir. Bu sayede gerçek ortamdaki nesnelerin ağırlık, düşüş etkileride gözlemlenebilmektedir. Hazır modeller çalışmada kullanılacak asıl model gerçeklenmeden önce ön çalışmaların yapılabilmesine de olanak sağlamaktadır.

Projede kullanılan Robovie R3 insansı robotu standart R3 robotunun farklı bir versiyonudur. R3'nin 12 eklem açısına sahip kolları ve birbirinden bağımsız hareket edebilen 5 parmağı bulunmaktadır. Robotu kontrol edebilmek ve hareketleri gerçekleyebilmek için yazılımlar bulunmakta ama hiç biri 3 boyutlu bir görsel sunamamaktadır. Bu ihtiyacı gidermek için Gazebo ortamında R3 robotunun özelliklerine göre bir simulator yazılmıştır. Simulator için fiziksel R3 robotunun vücut ölçüleri hesaplanıp SolidWork ortamında 3 boyutlu modeli çıkarıldı. Gerçek robottan farklı olarak modelde parmaklar kullanılmadı. Bu model Gazebo ortamında kullanılan dosya formatına çevrildi. Modelin Gazebo ortamında kontrol edilebilmesi ve Türk işaret dili hareketlerinin gerçeklenebilmesi için "plugin" adı verilen C++ kütüphaneleri oluşturuldu. Model kütüphanesi(plugin) modelin gerçeklenen el,kol ve baş eklemlerini kontrol edip limitlerine göre oynatabilmektedir. Diğer yandan kullanıcının kolay kullanımı ve hareketleri kaydedebilmesi için grafik arayüz kütüphanesi(plugin) yazılmıştır. Bu plugin kullanıcıya görsel bir arayüz sunmaktadır. Kullanıcı arayüz üzerindeki kaydırıcılar(slider) ve döndürme kutularını(spinbox) kullanarak robotun açılarını kontrol edip oluşturmak istediği hareketin durumlarını (state) kaydedebilir, sonrasında oluşturduğu hareketi simulator üzerinde gözlemleyebilir ve fiziksel robota aktarmaya uygun formatta hareketin çıktısını alabilir. Hareketin çıktısı robotu kontrol etmek için kullanılan Roboviemaker2 yazılımına uygun şekle çevrilerek fiziksel robota aktarmadan son bir kontrol edilmesi sağlanmıştır. Bu format üzerinde durum(state) açıları gözlemlendikten sonra fiziksel robota aktarılabilir. Diğer yandan kullanıcı Roboviemaker2 programı ile üretilmiş dosyaları ya da daha önceden simulator ortamında gerçeklediği hareketlerin dosyalarını simulatore yükleyerek oynatabilir.

Simulator ortamında kaydedilen hareketerin videoları android ortamında geliştirilen bir çatı yazılıma(framework) yüklenerek kullanıcılar üzerinde test edildi. Bu yazılım üç ana bölümden oluşmaktadır. İlk kısımda katılımcının ad, yaş, cinsiyet gibi demografik verileri alınır. Bu sayede testin yapıldığı katılımcı grubu analiz edilebilir. İkinci kısımda kullanılan uygulamaya göre eğitim kısmı bulunur ve uygulamayı kullanımı ya da uygulama içindeki işaretleri öğretilir. Son kısımda ise uygulamaya çoktan seçmeli sorular ile test yapılır. Bu yazılım ile araştırmacıların test yapabilmesi kolaylaştırılmıştır. Bu çalışma kapsamında da yazılımın bir versiyonu kullanıcılardan gerekli demografik datayı aldıktan sonra, çoktan seçmeli bir işaret dili testi ile simulator videolarındaki hareketleri kullanıcılara sormaktadır. Arka planda kullanıcıların doğru ya da yanlış seçimleri, seçim hızları gibi bilgiler değerlendirilmek üzere toplanmaktadır. İkinci bir versiyonunda ise işaret dili bilmeyen kişilere önce eğitim kısmında işaret dili kelimelerini işaret dili öğretmeni ve iki farklı robot platformunun videoları ile göstererek öğretir. Bu kısımda her hareketten sonra kullanıcıya robotların hangisinin hareketi öğretmeninkine daha benzer yapabildiği sorulur. Test kısmında ise öğretilen işaret dili kelimeleri robot platformları ile kullanıcıya sorulur. Bu versiyonda fiziksel robotların işaret dili üzerindeki performansları hakkında bize bilgi vermektedir.

Bu çalışma kapsamında 4 temel test gerçekleştirildi. İlk olarak geliştirilen simulator ortamında Türk işaret dili hareketleri gerçeklendi. Hareketleri gerçekleme sırasında tutarlılık sağlamak için Türk işaret dili sözlüğü baz alındı. Geliştirilen simulatorde şimdilik robotun parmakları yapılmadığından, parmakların en az kullanıldığı hareketler seçildi. İkinci aşama olarak gerçeklenen hareketler Robovie R3 robotunun kullandığı dosya formatına çevirilerek fiziksel robota aktarıldı. İşaretlerin fiziksel ortamda gerçeklenmesi incelendi. Üçüncü olarakta simulator ortamında kaydedilen videoların eklendiği çatı yazılımı (framework) işaret dili bilen işitme engelli çocuklar ile test edildi ve simulatörün başarımı gözlemlendi. Son test olarakta iki fiziksel robotun işaret dili hareketleri üzerindeki performanslarının video kayıtları çatı yazılıma eklenerek karşılaştırıldı.

Teslerde elde edilen sonuçlar simulatörün hareketleri gerçekleme ve proje kapsamında kullanılabilirliği üzerinde etkili olmuştur. Hareketlerin normalde kullanılan yöntemlerden daha hızlı ve düzgün bir şekilde gerçeklenip robota aktarılabildiği görüldü. Bu sonuçlar gelecekteki çalışmalar için bizi motive etti. Bir sonraki çalışma olarak Robovie R3 robotunun parmakları ve tekerleklerinin simulator ortamında gerçeklenmesi ve daha karmaşık hareketlerin yapılabilmesi amaçlanmaktadır.

1. INTRODUCTION

Computer simulations, creating environments and objects in 2D or 3D models have an important role in research areas. In many research area, experts want to see measured effects in a visual model to analyse and see the complex situations. Robotic is one of the significant area which need to use simulators because robots are mostly expensive gadgets to own and study on. It is crucial to create movements in a visual area and then transfer it to physical robot to prevent unwilling damages in physical devices. Robot simulators also have major roles such as their utility in research, potential for low cost training and adoption of new technology [5].

Robots are widely used in industry, military purposes and education. Its essential testing and modelling them in simulators. Education of sign language has a considerable usage of humanoid robots. Verbal education has many advantages and also application, but sign language need to use two hands and upper part of the body to communicate. Development of humanoid robots provide an interest on most researchers to use them in sign language education. During the verbal communication, people use their hands and body consciously or unconsciously. These gestures are the basis of the sign languages [6].

1.1 Purpose of Thesis

The presented work in this thesis is part of "Robot Sign Language Tutor" project [7], and supported by the Scientific and Technological Research Council of Turkey under the contract TUBITAK KARIYER 111E283. There is no simulator for the R3 humanoid robot which is used in the project. This work provides a realistic 3-D simulator for the R3 robot, which can produce both the virtually embodied version of the robot, and also transfer the actions produced on the virtual robot to the real robot with minimum data loss. It also carries out mobile games to measure effectiveness of the simulator and can be used as a tool to compare and study the effect of embodiment of the humanoid robots in sign language tutoring. In additionally, it aims to derive a mobile framework that capable of testing different test scenarios so we examine quality of signs which performed on robots and simulator.

1.2 Virtual Embodiments

There are lots of commercial and open source unmanned vehicle simulators.Simulators supply rapidly test algorithms, perform regression testing and design robots. Most of them include 3D environment with physic engines and model the real robots and situations. It is a mandatory thing to have 3D environment to express sign language words. In this work Gazebo simulator environment is selected to create robot simulator. Gazebo has a 3D environment which include OpenGL based visualization and ODE physics engine. It can simulate populations of robots in different kind of indoor and outdoor environments, efficiently. It is an open source software and has vibrant community. There are lots of models which can be used to interaction and also development of user's own robot [8].

1.3 Sign Languages

Communication is a major requirement for human life. People who hearing impaired or autistic cannot communicate verbally. Sign Language is a second option for these people and their families. It is a visual language which use two hands and upper body movements. Every culture and its verbal language have their own expressions , dialectal. These differences cause necessity of special sign languages. Turkish Sign Language has its own alphabet, vocabulary and grammar structure. TSL is widely used in different part of the Turkey so hearing impaired people can communicate with each other [9, 10]. To support education and therapy of hearing impaired children, gaming-based solutions are developed such as CopyCat a vision based interactive game to help in teaching American Sign Language [11, 12]. The ICICLE (Interactive Computer Identification and Correction of Language Errors) project focused to create lectures and guidelines for hearing-impaired children with computer-aided commands [13]. There are also many other studies to support the usability and education of sign languages [14-16] and additionally several of them use humanoid robots for this purpose [17, 18].

1.4 Research Questions and Hypothesis

In this study, we explored several questions;

- Is it possible to implement TSL words correctly on a Robovie R3 simulator environment?
- Can we transfer simulated TSL words to physical robot with minimum data loss?
- Is it a faster way than implementing the signs directly on the physical Robovie R3 Robot platform? Are naive users able to operate system easier?
- How is the intelligibility of TSL words on different robot embodiments?

The possible outcomes of the thesis:

- Robovie R3 simulator represents the 12 DOF (Degree of Freedom) in the upper body of the physical R3 humanoid robot including real size measurement of the body and limbs, so it is as good as physical humanoid R3 robot on performing TSL words.
- Signs are visually created on simulation environment. Without having trouble with physical robot, user can create any motion and reorganize it to make more suitable. It accelerates implementing time. Besides it is easier and safer to visually create the motion on the simulator and send to the physical robot for especially non-expert users.
- We can measure the comprehensibility of TSL words on simulator by testing them with a mobile game on participants who has advanced sign language skills. We assume that results will be promising and motivate the use of the simulator in our future studies.
- We can compare the performances of the virtual and physical embodied versions of the same humanoid robot in sign language tutoring and study the effect of embodiment in sign language tutoring.

2. REVIEW OF LITERATURE

2.1 Physical Embodiment Platforms

Actual physical shape by having embedded sensors and motors can be defined as physical embodiment of a robot. There are different levels of embodiments in HRI studies [19, 20]. We will explain two humanoid robot as physica embodiments.

2.1.1 Humanoid robot Robovie R3

Robovie R3 is a humanoid robot which is designed by Vstone (a Japanese company). It is 1.08 m tall and 35 kg and have 11 touch sensors through its body, 2 camera for eyes, 2 mono microphones for ears and a speaker for its mouth. Standard R3 platform has 17 DOF (degrees of freedom) but our modified version has 29 DOF in total. Four DOF are in each arms, three DOF are in neck, two DOF are in each eyes and two DOF are in wheels. Also our modified version has DOF in wrists and fingers. It is capable of moving fingers independently. This fingers make easier to perform TSL words. R3 has also a LED mouth which can show a smile or sad face expression. It gives feedback while playing interactive games with children. It is not a small sized robot as a toy, its size is similar to a child, so children can accept it a peer while playing games.

R3 has RobovieMaker2 software and VSRC003 SDK to control and implement actions. These software do not have a visual simulation but provide full control of R3's capabilities. Robovie R3 is shown in figure 2.1 while performing TSL words.

2.1.1.1 RobovieMaker2

It is a dedicated software to control CPU board "VS-RC003". It can be used all robotic devices which includes this CPU board and our Robovie R3 has also "VS-RC003". RM2 can set servomotors, controllers and expanded boards. It has also a simple graphical user interface (gui) to implement poses and motions of robot. Created poses

Figure 2.1: Robovie R3 performing TSL word baby.

can be transferred to physical robot, but there is no visual 2D or 3D expression of motions in program.

In Fig 2.2 RM2 software with hand movement demo is shown. In right side of the gui is motion area, it is like a flow chart. Left side is a pose area, in every pose in motion area can be configure from pose area. Poses have their states for each angles and step count to reach this pose. RM2 has also condition, break blocks to perform complex actions. After creating motions, it can save output as a text file. It has a special format and we developed also a converter to create simulation result in this file format and transfer it to RM2 software.

2.1.1.2 VSRC003 SDK

The VS-RC003 is CPU board which is used in Robovie R3 and VSRC003 software development kit is implemented to command the servo motors and controllers of the robot. User can upload, play, stop, cancel motions with VSRC003 SDK. It can also reach the memory cells of the CPU board and reconfigure the default actions of

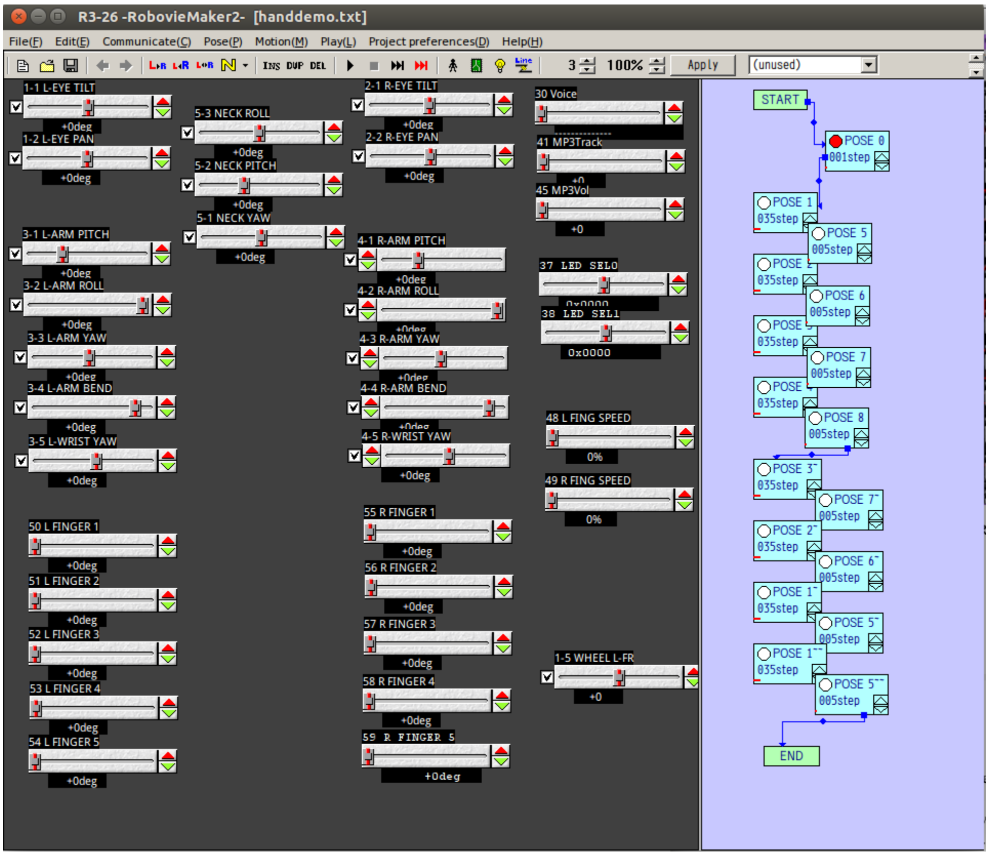

Figure 2.2: RobovieMaker2 software.

Robovie R3. Besides all this features, it have also no visual simulation to see the motions.

2.1.2 Humanoid robot Nao H-25

Aldebaran Rabotics manufactured humanoid robot Nao H-25 in 2005. It has a reasonable price with multiple features. Nao is 0.57 tall and 4.5 kg, so it is small sized, lightweight robot. It can perform smooth and autonomous movements. Communication with robot can be established over WiFi or Ethernet port.There are 2 gyrometers and 3 accelerometers on it.

Nao totally has 25 DOF on its body. 11 DOF are in lower part of the robot. There are 2 DOF in angle of each leg, 1 DOF at the knee and 2 DOF at the hip, legs and pelvis. Upper part has 14 DOF. Each arm has 2 DOF at the shoulder, 2 DOF at the elbow, 1 DOF at the wrist and 1 additional DOF is for the closing fingers. The robot head also can rotate about yaw and pitch axes. Nao also has microphones and two loudspeakers on it. The robot has a rich development environment. Naoqi framework

Figure 2.3: Humanoid robot Nao H-25.

and choreograph programs are make easier to use this robot. Details of this programs will be explained in below part of this chapter [21,22].

2.2 Virtual Embodiment Platforms and Simulator Environments

The usage of simulators in research can be too many variations. Testing effects of situations, modelling real environments have different requirements. Some simulators provide only calculations and 2D result visualizations and also graphic charts. More developed ones have visual 3D embodiments environments and physic engines. We research for a proper one and examine several well known simulator environments. In this project Gazebo simulator is used to visualize R3 robot's virtual embodiment.

2.2.1 USARSim

Unified System for Automation and Robot Simulation (USARSim) is based on Unreal engine. It has three different versions with different Unreal engine versions. Unreal engine allow to create complex environments that includes actors, Unreal Collision engine and networking. It is enhanced mainly as a game engine for developers [23, 24]. It simulate visual environment and supports bipedal and wheeled robot. In USARSim environment, robots are programmed or controlled over a network connection. This simulator is mostly used in disaster scenarios. Robots can be stopped by a brick or lose control on wet surface. Environments of this simulator mostly include different kind of obstacles to pass over [5, 25].

2.2.2 MATLAB

MATLAB (matrix laboratory) is a fourth generation programming language and computing environment. It is a commercial tool and developed by MathWorks. MATLAB allows matrix manipulations, implementation of algorithms, plotting data and also provides interface to include codes from other languages such as C, C++, Java [26]. It has many toolboxes to support visualization, robot controllers, communicating with other simulators. Multi-robot teams used MATLAB to simulate unmanned systems for control algorithms. According to Craighead, MATLAB is successfully used for UGV(Unmanned Ground Vehicle), UAV(Unmanned Air Vehicle), USV(Unmanned Sea Vehicle), UUV(Unmanned Underwater Vehicle) simulations [5].

2.2.3 Rviz

Rviz is a 3D visualizer which works over Robot Operating System. It displays sensor data and state information from ROS [27]. User can check the joints of the model with a simple joint GUI of Rviz. Unified Robot Description Format (URDF) files are used in Rviz. It is an XML format for representing a robot model and widely used in ROS [28]. Rviz allows user to manipulate model, camera and world parameters, so different situations can be visualized. However, It does not have a physic engine, so gravity effect can not be seen on Rviz.

2.2.4 Webots

Webots is designed to be used at robotic research and teaching institutes. It is a commercial tool and developed Cyberbotics Ltd. Webots allow user to import any 3D models in its scene which is modelled in VRML97 standard [5]. Any type of mobile robots can be modelled and simulated including wheeled, legged and flying robots. User also can create large worlds and Webots will optimize it to enable fast simulations. Webots provide a complete library of sensors and actuators. For example, more than one camera can be placed on the same robot to analyse 360 degree vision or stereo vision of the system. Some robotic devices including articulated mechanical parts requires accurate simulations. Webots uses Open Dynamic Engine(ODE) to have more precise simulations. Robots can be so slow in real world but Webots can simulate them 300 times faster in simulation environment to show results quickly. When the simulation and testing completed, data can be transferred to the physical robots from the Webots. Programming interface of Webots supports C, C++, Java languages and also any third part software through TCP/IP. Webots have many applications since 1998 for educations and research purposes. These applications can be categorized as;

- The multi-agent simulations
- Simulating intelligent robot behaviours
- Performing complex mobile robot motions
- Designing and shaping mobile robots

Webots runs on Windows, Linux and Mac OS X and it is commercially available from Cyberbotics Ltd. [29, 30].

2.2.5 ICub simulator

ICub is a new open-source humanoid robot developed as a part of European project "RobotCub". Physical iCub robot's height is around 105 cm, weights approximately 20.3 kg. It has 53 degrees of freedom in all body of robot. ICub simulator is designed with physical robot's data, so it has same measurements on simulator environment. ICub simulator uses ODE (Open Dynamic engine) to simulate physical interaction with objects and simulation environment. It is also uses YARP (Yet Another Robot Platform) protocol which is also used in physical iCub robot, so simulator can be controlled via the device API or across network as the same way with physical robot. It is a particular simulator to study with iCub robot [31, 32].

2.2.6 Nao H-25 Choreograph

Nao H25 is a small sized humanoid robot which is produced by Aldebaran Company. Company also creates a Naoqi framework to access physical robot and program it. Naoqi module have a graphical environment called as Choreograph for simulating actions and than transferring them to the physical robot. It is capable of performing fine-tuning of complex joint and Cartesian motions. Programs can be designed event-based, sequential or parallel for choreograph. It also procure a time line, so user can performs actions within a schedule logic. It is a commercial and individual simulator for Nao H-25 [21, 33].

2.2.7 Gazebo

Gazebo is a Linux-only open source 3D robotic simulator and developed in Robotics Research Labs of Southern California University. It is designed to simulate the dynamic environments that robots can involve. Every object in the environment has mass, velocity, friction etc. to accurately produce the realistic situations [8].

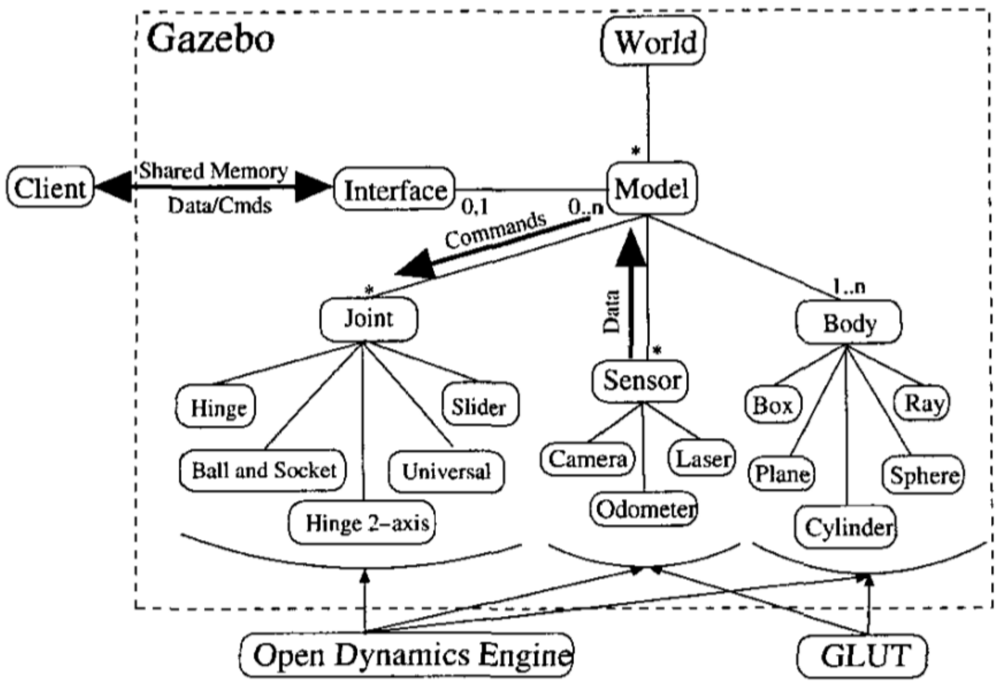

Figure 2.4: Structure of Gazebo components [1].

Structure of Gazebo is shown in figure 2.4. Gazebo take data from model sensors and apply them to joints to simulate the body in visual world. It can also have plugins to interact with the model. Details about plugins will be explained in next chapter.

2.2.7.1 Player and Stage

Player is a network device server and Stage is a complex 2D simulator for multiple mobile robots simulation. They have been developed since 2001 and used in many projects in industry and academia. Gazebo is developed to compatible with Player project. It is designed to be a 3D simulator which can reflect the behaviour of physical counterpart. Gazebo is not a fully replacement of Stage, because in 3D environments, user only use a few robots in Gazebo, Stage supplies a robust and efficient simulator for large group of robots in 2D environment [34, 35].

2.2.7.2 Gazebo with ROS

Early versions of Gazebo is designed to work with Robot Operating System (ROS). ROS is an open source operating system which is capable to work with many type of robots. Hardware abstraction, device drivers, libraries etc. is provided by ROS. It uses inter-process communications so different sensors, drivers can communicate [36]. ROS launches Gazebo with environment and robots over the network.

2.2.7.3 Standalone Gazebo

Developers created a standalone version of the Gazebo with version 1.9 which do not need ROS. Gazebo has its own Ubuntu packages. It provides odometry range and camera sensors. Realistic environments, world physics, rigid body dynamics can be simulated in Gazebo. It requires a good CPU processor and graphic card because of 3D real time simulations [37]. It has a lot of prepared models in packages. In Fig.2.5, we see a PR2 robot, a house, a fire hydrant and a construction cone. PR2 robot has a sensor and scanning the environment. Different kind of usage scenarios can be implemented in Gazebo.

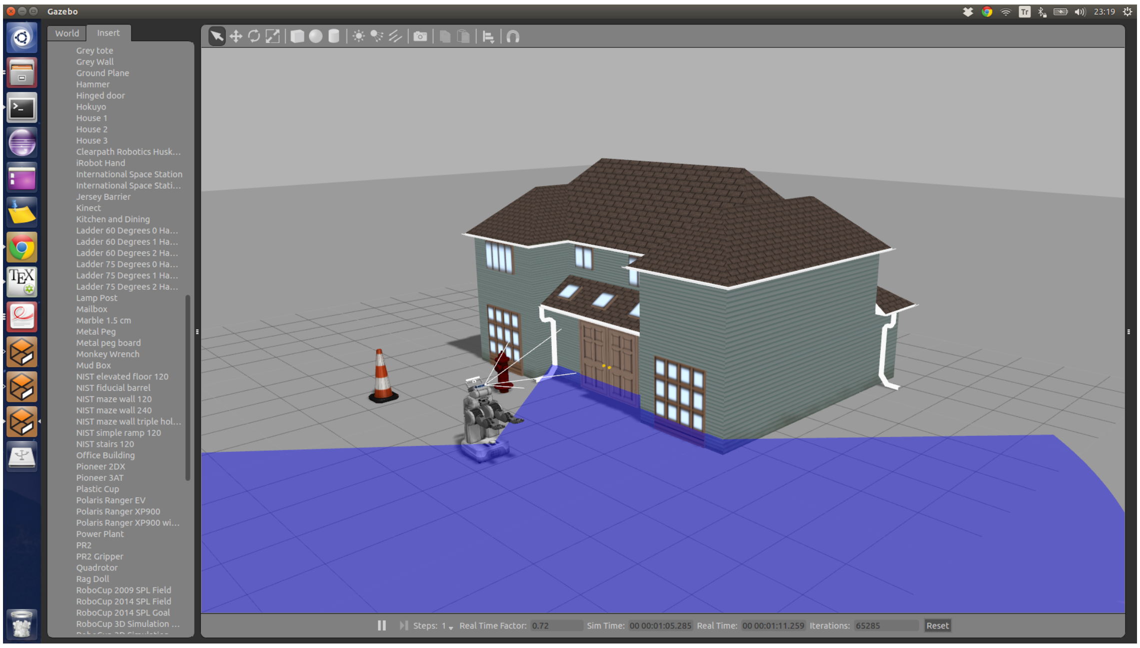

Figure 2.5: PR2 robot is scanning the environment.

2.3 Turkish Sign Language (TSL)

People use their hands and body to show or sign some objects while even during the oral communication. According to Miles, first cue of TSL is seen in Yunus Emre's poetry, He talked about giving signals with hands [38]. This can be only the signs, so more clear information about TSL can be shown in Ottoman Palace in the period of Fatih Sultan Mehmet and government members need to have trusted people who will work during the secret meetings. A person who can not hear anything is the best one to serve during the confidential gatherings. These people called "mute"(dilsiz) and have important jobs in palace and Bab-ı Ali. Later on, TSL become a communication system and it accepted as prestigious language. It is used not only hearing-impaired people, but also used by women in the harem and by sultan in the personal communication [6]. In 19th century, first special school was established and sign language alphabet with Ottoman Turkish is derived from French sign language alphabet [39]. During the progress of TSL education and development, some communities and schools are established to help hearing-impaired people. First master thesis is completed in Hacettepe University at 2001, later on government officially constituted Turkish Sign

Language dictionary at 2005 [40]. There are several studies in Turkish Universities to improve usage of TSL [41, 42].

Turkish words (in oral language) are formed of ’phonemes’, and besides TSL signs are consist of shape, movement and location of hand. These definite component collection effectuate TSL, as well as limited phonemes compose Turkish words [43]. In oral language letters’ order is important for the meaning of the word, such as "book"(kitap) and "bootee"(patik) have same letters but different meanings. Similarly in TSL some words have same sign and also their hand shape and orientations are identical, but the beginning and end locations are different just as "free"(serbest) and "sometimes"(bazen) in figure. 2.6 [2].

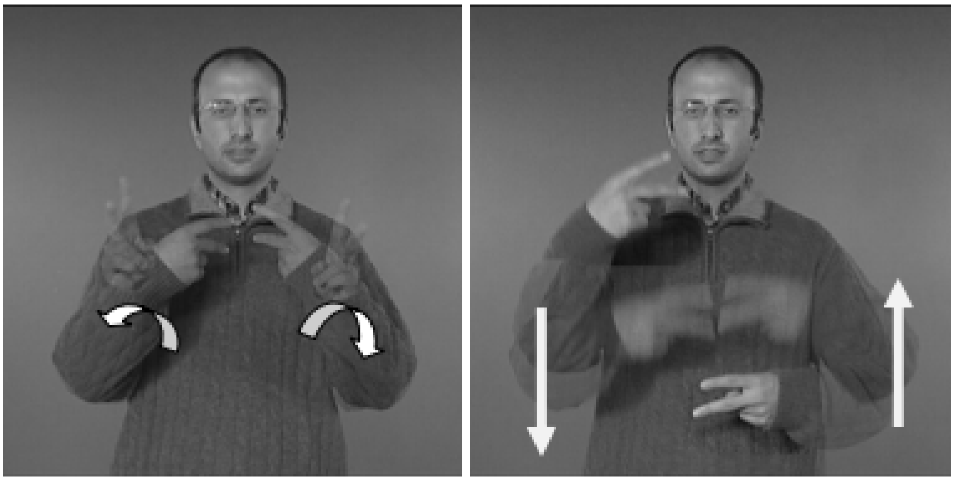

Figure 2.6: Same sign , different location in TSL: "free"(serbest) and "sometimes"(bazen) [2].

2.3.1 Robot sign language tutor project

In the beginning of project, signs were manually implemented on humanoid robot. We organized arms, hands and fingers to proper positions and angles. After recording signs, we showed them to sign language tutors to verify and finalize them. However this process takes approximately one and half hour depends on complexity of signs. One of the propose of this project is reduce implementation time and increase accuracy of signs while transferring gestures to humanoid robot.

As a part of this project, several interactive games are developed to teach sign language. Robots are used as a companion to help signs in games. iSpy-Using game is one of the interactive games. Experimenter shows flash card to child and robot, than they are try to explain sign in the flash card. In a order one tries to describe it and than other guess the sign. In current version of the game, only child guess the sign and preselected cards are used and this game will be improved with using Kinect camera, so robot can recognize gesture of child without any clue [44]. Story telling games are also created with using robots and flash cards. The robot tells a story using the signs the participant have already learnt. Tutor shows flash cards between the sentences and robot continue to story [45]. There are also mobile and web based survey and games which uses the videos of robots. In the survey, a tutor express a sign than participant is asked to select the matching robot video from a set of choices of other robot videos. Mobile games have the same principal but some version of mobile games also includes a training part to teach the signs [46].

Learning by demonstration (LfD) method is used to recognize the signs. Visual data of user is taken by Kinect and ASUS RGB-D cameras. Recognition of begin and end points of signs (action segmentation), learning from whom are basic problems of LfD [47]. At first, we used time to determinate begin and end points of signs, but every user performs signs in different speeds so we decided to use initial position as begin and end points. Data is collected from many participants and system trained. To have proper signs, we preferred only expert's data.

Human data converted to angles, but humanoid robots are not same with humans as kinematic. There are differences on shoulder and elbow angles such as people have 3 shoulder, one elbow angles besides our robot has 2 shoulder and 2 elbow angles. This correspondence problem have some solutions such as mapping, inverse kinematic [48] [49]. After solving correspondence problem, angles have to be filtered before sending them to robot.

There are many studies about converting human Kinect data to robot. Particle filter method is used mostly with multi-sensor systems, but some studies shows usage of this method on Kinect data to calculate joint angles [De Rosario et al., 2014]. In another research, performance of Kinect data and Kalman filter is compared with a commercial product. Results showed using Kinect data with Kalman filter method gives good result as much as commercial tool [50]. In our project, we developed a method based on Berger's study in 2011 [3]. At first, trajectory vectors are created from joint positions and than upper body angles are calculated. Joint are showed in figure 2.7.

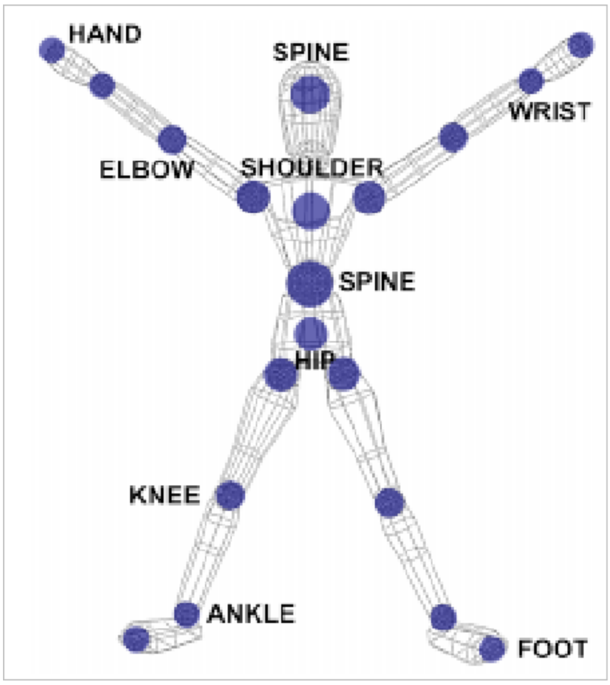

Figure 2.7: Joints of Human [3].

After calculating angles from Kinect data, we need to check them before transferring to physical robot. Simulator of robot is created to solve this problem and prevent unwilling damages on physical robot.

2.4 Android Based Applications

Mobile platform provide more interaction than a desktop computer because haptic feedback increase the interest of user. A mobile game can be a remarkable agency to improve the capabilities of children. There are so many commercial and free mobile applications for education and therapy of children. We will discuss three of them in this chapter.

2.4.1 Lingling learn languages

This application platform aim to teach words of selected languages with games. User can create and have a mascot in game, it makes funny actions during the game. Game has two main part, in first part application show daily limited words to user. When the all words are showed a few times and user accepts all of them, test part starts. In test part, mixed words asked with time limits and between the session of the tests, a funny simple game is played. In every test session, time limit decreased so user have to be more careful and fast to continue the game. It has many language support such as Spanish, Portuguese, French, Chinese etc [51].

2.4.2 My baby drum

"My baby drum" application goal is development of babies' sensibility. It has a colourful screen with different sized drums. Drums give haptic feedback and show animations to stimulate children's curiosity. User can play more than one drum at the same time, so it deliver an advanced feeling of touch. Application also provides many children's song to use while tapping the drums to make exhilarating performance. It is a commercial tool and more than one million people downloaded it from android application market [52].

2.4.3 Turkish Sign Language dictionary

Turkish sign language dictionary is a simple mobile application developed by hearing impaired students of Turhan Sönmez Meslek Lisesi. There are 1868 words in dictionary. Signs are captured with state pictures. Application does not give meaning of the words, it try to give equivalent sign of the word. It is designed for people who have hearing ability and want to learn TSL. They created this application using official TSL dictionary of Turkish Language Institute [53].

3. PROPOSED SYSTEM

An output of this work is simulator of Robovie R3 robot. Robovie R3 robot and developed simulator are explained and then mobile application which used to take opinion of participants about the quality of simulator are presented in this chapter.

3.1 Development of Humanoid Robot Robovie R3 on Simulator Environment

Gazebo simulator environment, provides a physic engine and 3D models to simulate objects. Robovie R3 virtual embodiment of simulator consist of a model and plugins. In Gazebo, we need a gui plugin to control robot and a model plugin which perform joint motions on model. There are lots of sample models which can be find in model library of Gazebo, but Robovie R3 is a new robot and we need exactly same sizes, so after creating motions we can test them in physical robot. We created our own model and plugins to develop R3 simulator.

3.1.1 SDF model of Robovie R3

Model files of Gazebo was similar to ROS model files. It was "URDF" file which is actually a special type of xml file consist of all part and joints of robot. Later on, they changed in file format and started to use "SDF" (Simulator Description Format) file. It is also an xml file originally designed for Gazebo. There are two basic files to describe model, one is "config" file which help gazebo to show model in model list, and other one is model's SDF file. SDFs are used in many files such as world files, robot files etc. Structure of SDF file can be seen in figure 3.1.

We measured part of Robovie R3 robot and used results to design model in same sizes. Every part can be implemented with xml tags in SDF but it is an exhausting way. We created our 3D model in Solidworks software. Solidworks can give output as URDF format with "sw_exporter" add-on. Output includes meshes,textures and robots(URDF) files.It has a tree structure which contains joints, rotation axes and coordinate axes. Figure 3.2 shows model in Solidworks environment.

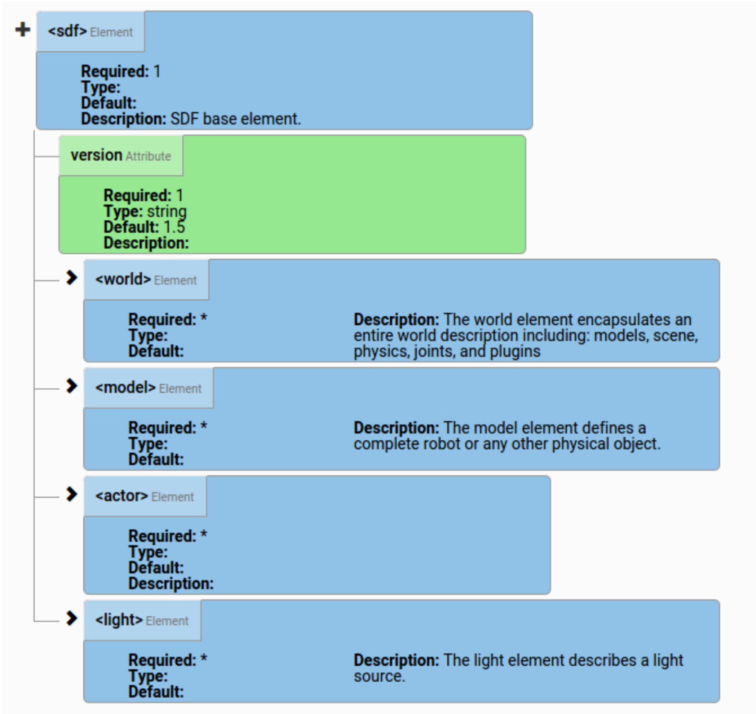

Figure 3.1: SDF file format [4].

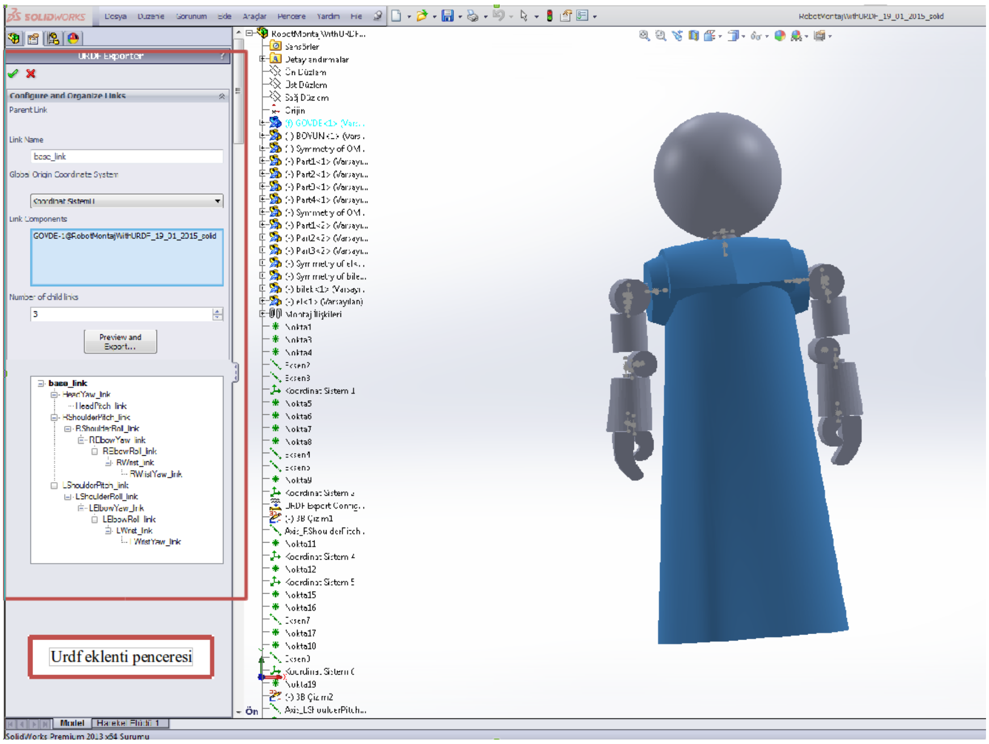

Figure 3.2: Model in Solidworks.

After URDF model is created, Gazebo can convert it to SDF format.In the project we need only the arms' and head' motions, so in the model we added joints of the head and arms. Fingers of the model are not implemented in this work. Model is shown in figure 3.3 while performing TSL words.

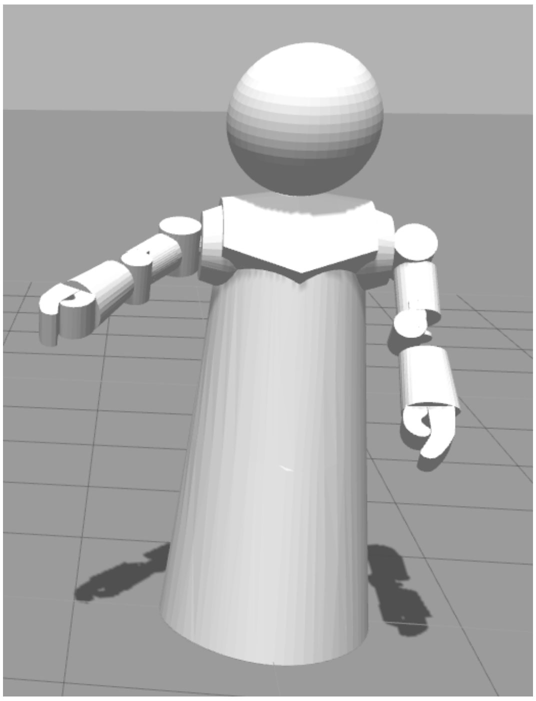

Figure 3.3: R3 model while performing TSL words.

3.1.2 Plugins of Gazebo simulator

Plugins allow user to control model, world or sensors in Gazebo. Plugins are shared C++ libraries and they added on models or worlds to interact with environment and models.

3.1.2.1 Model plugin of Gazebo simulator

Model plugin is added in model file to move joints during the simulation. It has an "OnUpdate" method which called every simulation time tick to update model. This plugin has a communication interface with gui plugin and it takes joint values from gui and perform them or take a file name from gui plugin than it read and calculate a complete motion to play on model. Model has 2 joints in head, 4 joints in each arm and these joints provide motion to model in simulator environment. Model joints can be seen in figure 3.4.

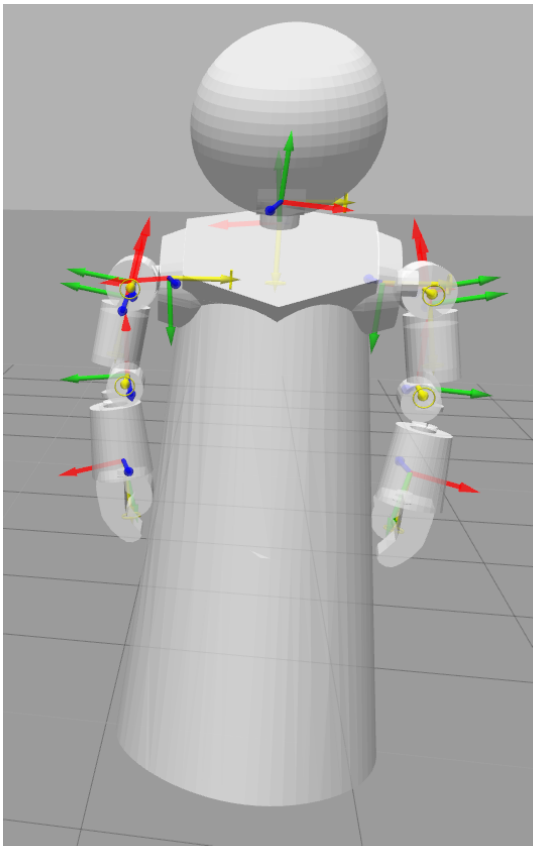

Figure 3.4: R3 model with joints.

3.1.2.2 Gui plugin of Gazebo simulator

Gui plugin is added in a simple world file which include model, ground and sun.It supply a graphical user interface over Gazebo platform, which includes buttons, sliders, text boxes etc. Gui items derive from QT objects, so every object can have a slot and signal to trig an action. Graphical user interface of plugin is shown in figure 3.5.

In gui, user can creates a motion file and save states of robot in file than play this file to perform motion.

3.1.2.3 Communication between plugins

Actions on gui are sent to model plugin over a communication interface. It is called as named pipeline. Model plugin creates this pipeline and in "onUpdate" method reads this to decide action. Gui plugin write down simple actions or a file name to the pipeline. Data has a simple format, if the first char of data is 0, that means it is a state data, if first char is 1 or 2, it is a file to perform a full motion. There are two number for files, because two type of file can be played on simulator. User can choose a RM2

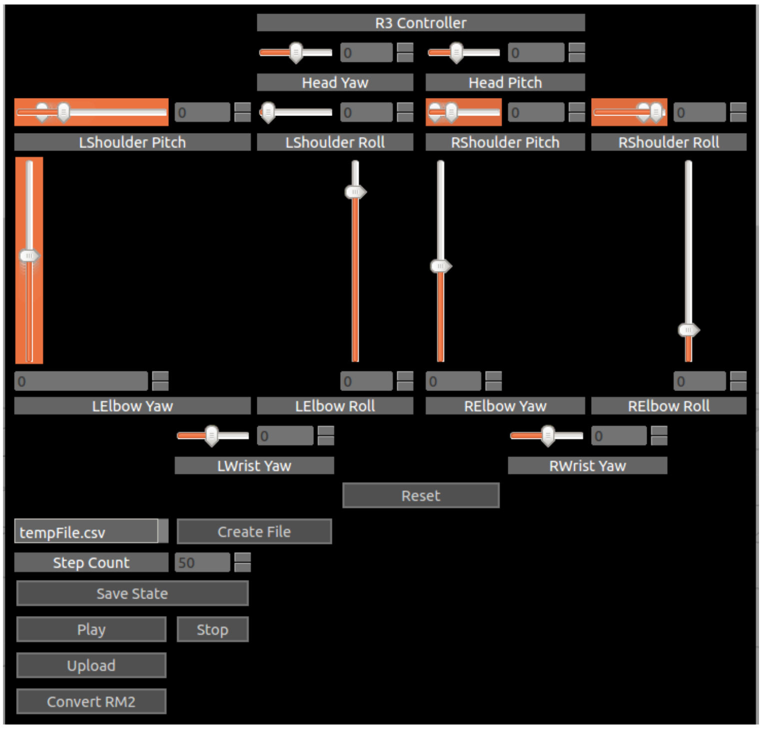

Figure 3.5: Graphical user interface of plugin.

file or motion file which is created on simulator. According to choice of user, it sends 1 or 2 to model plugin, so it can decode the joint values in file.

3.1.3 Simulator file to RobovieMaker2 file converter

Simulator can perform motions but before transffering simulation data to physical robot we need to be sure, it is valid for physical robot, so we created a file converter. After creating motion file in simulator, user can convert it to RM2 format and check it. Robovie R3 also do not accept different file formats, so converting RM2 format makes easier to transfer data to Robovie R3. User can also upload RM2 files to simulator, it can decode and play the RM2 files.

3.2 Android Based Sign Language Games

Mobil games can support education and therapy of children for different subjects. Interactive robotic games in mobile devices are used to teach Turkish Sign Language. In a previous study, we verified that robot's video based games can be effective as games with physical robots [10]. It is significant to create an interface which is designed with Human-Computer Interface principles, so people can easily adapt an use it. We developed a unified framework which is designed with a proper interface for the children. We make interviews with a pre-school teacher, a designer and researchers. Than we create first sketches of the game. They approve this sketches and we create the application.

Implemented framework has three main part, First part is collecting demographic data of user such as name, age, gender etc. as in figure 3.6. It is similar to a typical questionnaire or a survey. In second section of framework is training part of game. In this part, we can add education videos. For example in sign game, robot and human tutor teaches signs to user. Last section of the game is test part. In sign game, it displays signs with robot videos and four choices. Three of them is sign words, one is pass option. It is created to play games with children, besides it provides data for researchers to analyse actions of user in game such as right, wrong choices, action times.

Figure 3.6: Collecting demographic data.

3.2.1 Sign game for beginners

This game is implemented over the framework. It is designed for beginner sign language users. In training part of the game, 5 sign words are showed with tutor and robot videos. First human tutor shows sign, than Robovie R3 and Nao robots perform same sign. After every three videos of each sign, game asks which robot makes signs more similar to human tutor. We want to take their ideas about robot's performance. In figure 3.7, "mother" sign is shown in training part of the game.

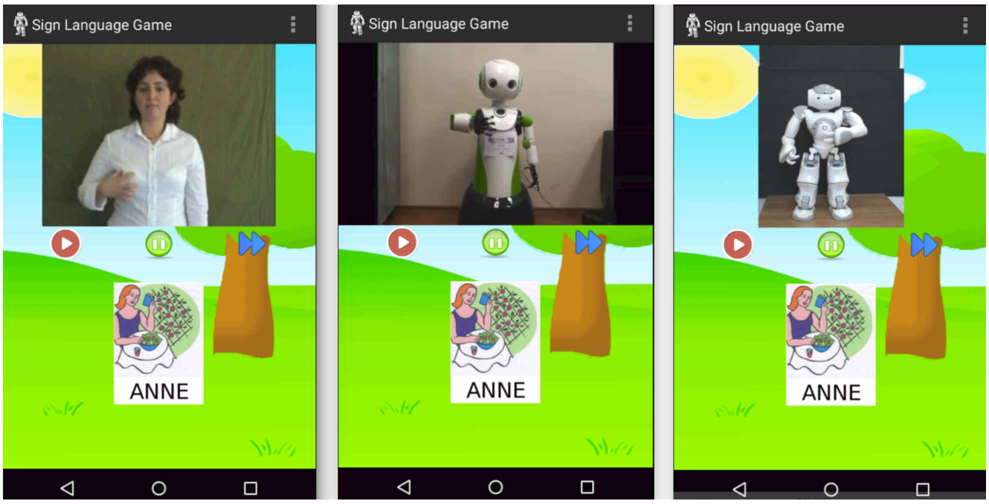

Figure 3.7: "Mother" sign is shown with human tutor and two robot platforms.

In the test part of this game, 5 TSL words which is taught in training part are performed with mixed videos. User have four different choice in test part. One choice is correct one, two other options are taught words in training part and last choice is an irrelevant word. In figure 3.8, multiple choice test questions of game is shown. The detailed results of this game will be in experiment chapter.

3.2.2 Sign game for advanced users

We also developed an application for advanced sign users. It uses same framework, but this game has no training part, user directly play the test part of the game. In test part 10 selected TSL words asked with four choices. In this game one choice is pass option and one choice is a similar one to correct words, so if the physical or visual embodiments of robots make sign, ambiguously. Result will be more clue about embodiments' performance. These game has different versions with physical Nao and

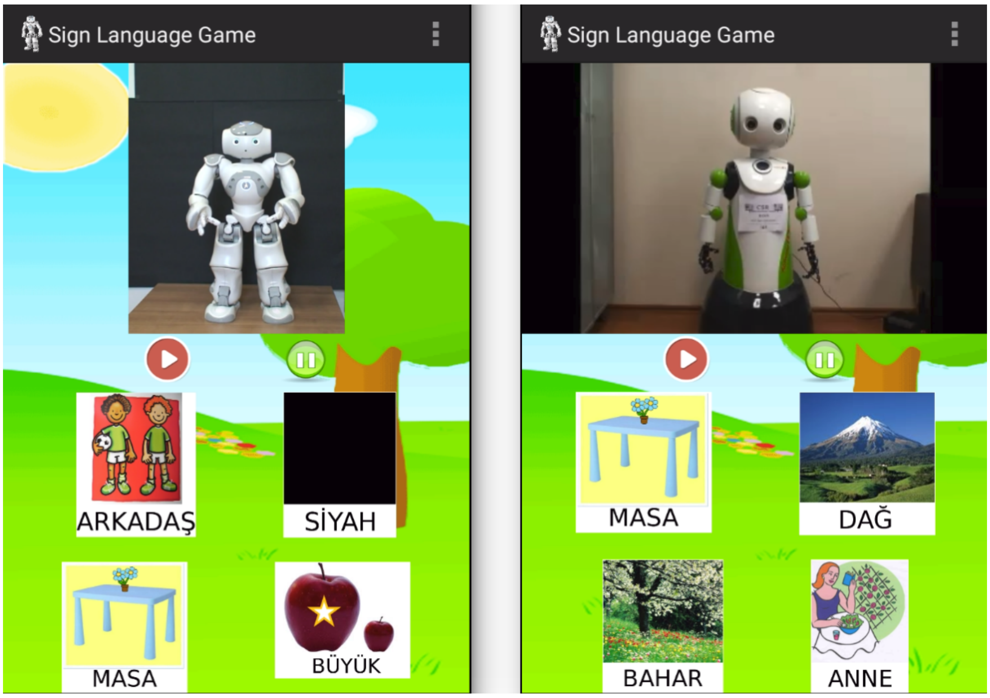

Figure 3.8: Multi-choice test with different robots.

R3 robots videos and There is also a version with visual embodiment of R3 robot's videos. A game test question can be seen in figure 3.9.

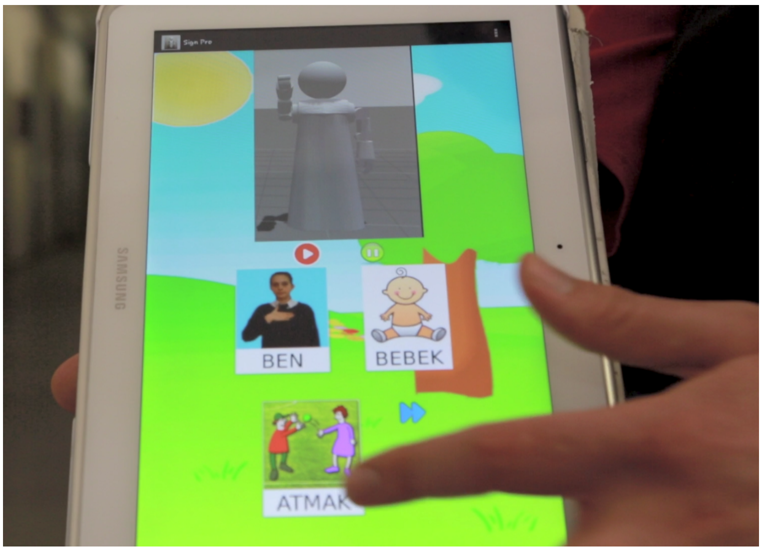

Figure 3.9: R3 Simulator Game

It is tested with hearing-impaired children with advanced sign language skills. Results of this experiment is explained in next chapter.

3.3 Proposed System Overview

System capable of moving arms and head, so it can accomplish not only TSL words but also to create anything including arms and head. Generated virtual or physical robot embodiment videos are added to mobile games to analyse the capability of embodiments. Full Simulator system is shown in figure 3.10 while robot demonstrating TSL word "mountain".

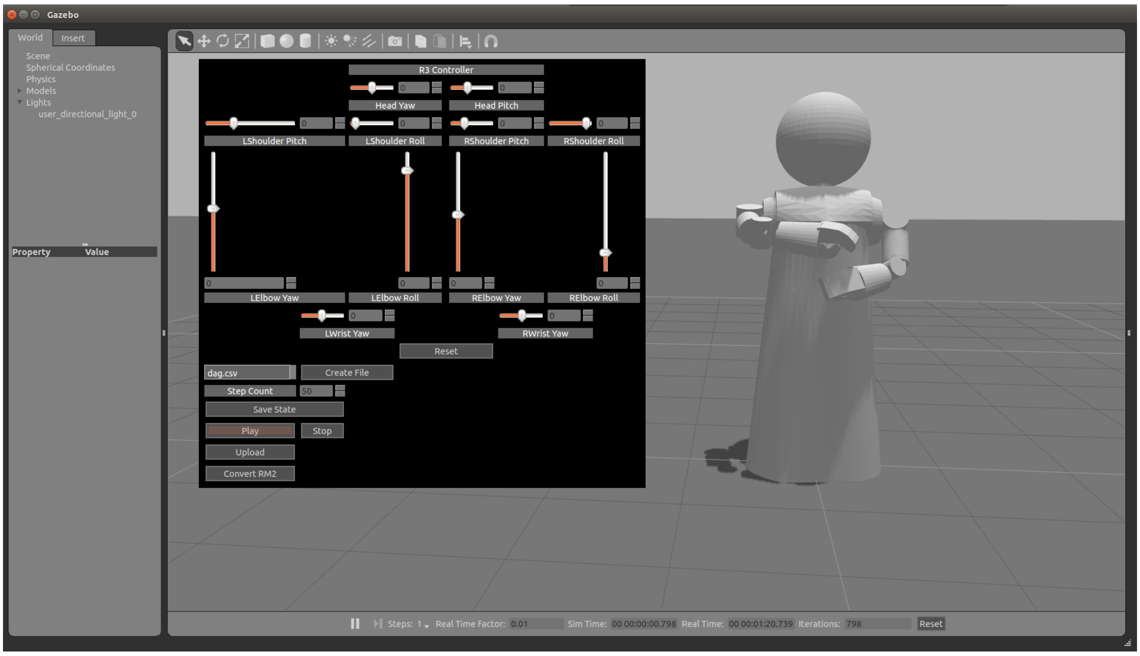

Figure 3.10: Simulation System Overview.

R3 Simulator embodiment consist of model and plugins of Gazebo. System is controlled with gui plugin and actions on robot provided with model plugin. Motions are saved in our own format or converted to RM2 format to use in RM2 and physical robot. Schema of system is shown in figure 3.11.

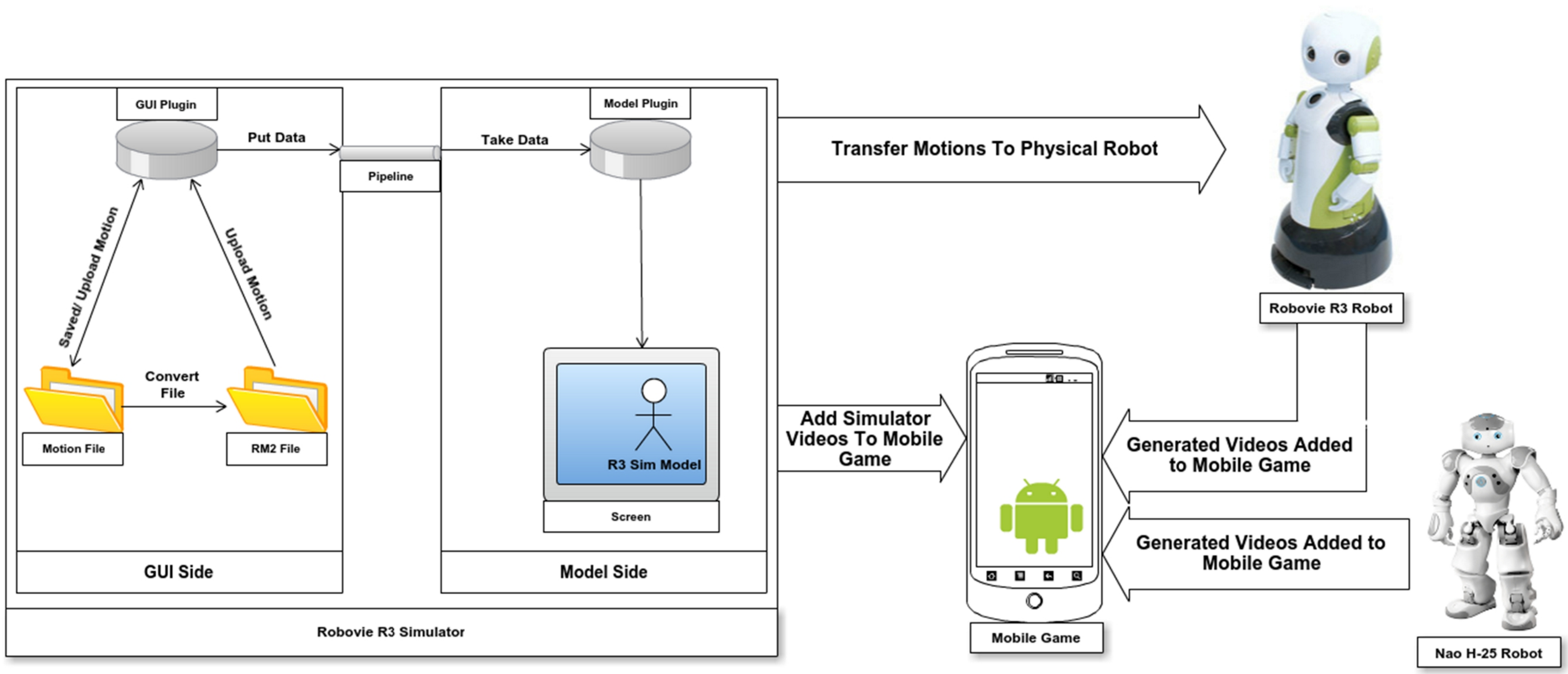

Figure 3.11 : Schema of System.

4. EXPERIMENTS AND RESULTS

Due to not having 3D visual simulator of Robovie R3 robot, in this thesis we develop a virtual embodiment of R3 to implement TSL signs before transferring the physical robot and test this tool using TSL words and interaction mobile games. Before the study go ahead, some prestudy is done to understand feasibility and usefulness of the idea and experiment setup. The main aim of these experiments is to implement and perform TSL words on virtual embodiment of R3, transfer them to physical robot. In additionally, TSL words which is played on simulator environment recorded and added a mobile interaction game to measure understandability of signs. Implementation TSL words on simulator and transferring speed of them to physical robot explored with results of experiments.In experiments, Robovie R3 robot and mobile devices are used, experiment tested on hearing impaired children who have advanced TSL knowledge. The experiment setups are introduced below.

4.1 Implementation of TSL Words on The Simulator

Robovie R3 simulator does not have only one dedicated aim, but we focus on Turkish Sign Language in this study, so implementing TSL words on simulator is our first experiment.

4.1.1 Research question and hypothesis

In this experiment, we started exploring a simple question:

- Is is possible to implement TSL words correctly on a Robovie R3 simulator environment?

Our hypothesis is:

- Robovie R3 simulator has 12 angles in upper body and it is a humanoid robot simulator, so TSL words can be performed correctly on Robovie R3 Simulator.

4.1.2 Experiment setup

In this experiment, we used TSL dictionary to learn basic words and transferred these words on simulator. Every word has a few basic states, so we identified this states and saved them on simulator. 10 TSL words are implemented on simulator these are "spring", "mother", "baby", "table", "to throw", "me(I)", "big", "mountain", "come", "black". A file is created and states of sign are saved for every word. One of the performed sign file is shown in figure 4.1. There are 12 angles and a step count value to pass next state.

HeadYaw	HeadPitch	LeftShoulderPitch	LeftShoulderRoll	LeftElbowYaw	LeftElbowRoll	LeftWristYaw
0	0	0	0	0	0	0
0	0	91	47	0	-130	0
0	0	91	-5	0	-79	0
0	0	0	0	0	0	0

RightShoulderPitch	RightShoulderRoll	RightElbowYaw	RightElbowRol	RightWristYaw	StepCount
0	0	0	0	0	50
0	0	0	0	0	50
0	0	0	0	0	10
0	0	0	0	0	50

Figure 4.1: "Mother" word file of Robovie R3 Simulator.

During this experiment, collisions over robot can be detected, so we straightened the signs. Experiment with implementing "black" word can be seen in figure 4.2. We can rotate model and observe collisions during the simulation.

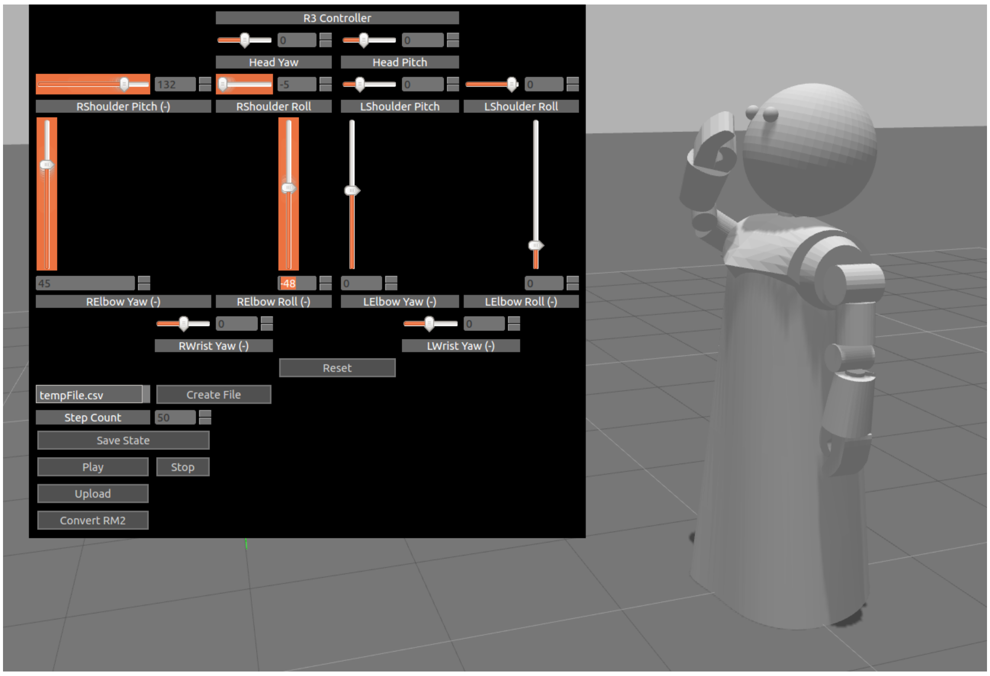

Figure 4.2: Observing the collisions while robot performing word "black".

10 selected words are performed on simulator using 12 joints of robot.

4.1.3 Results

We chose these 10 TSL words particularly, these words do not need finger movement to show and easy to understand. Robovie R3 simulator demonstrates selected TSL words as correctly as TSL dictionary and we examined accuracy of the signs in another experiment with a mobile game. Details of this study will be explained in last experiment.

4.1.4 Discussions

In Sign Language hands and upper body are used and in some signs fingers are also important and in design of the simulator we didn't implement the 5 finger of Robovie R3. Simulator is designed to protect robot from collision and damage while showing the signs. Fingers of robot can be implemented in simulator but it is not a vital case.

4.2 Transferring The Simulator Data to Physical Robot

4.2.1 Research question and hypothesis

The questions for this experiment were;

- Can we transfer implemented TSL words to physical robot correctly?
- Is it a faster way than usual implementations of signs on Robovie R3 Robot platform? Are naive users able to operate system easier?

Our hypothesis is:

- Created signs' motion files converted to RM2 format, so we can upload them to physical Robot via Robot's computer. Signs are first visually created on simulation environment. Without having trouble with physical robot, user can create any motion and reorganize it to make more suitable. It accelerates implementing time. Besides it is easier to non-expert user to implements signs and send them to physical robot.

4.2.2 Experiment setup

In this experiment, we implemented basic signs such as "side", "forward", "up" as a beginning. Later on we performed complex signs on simulator and transferred them to physical robot. After playing signs on simulator, we converted motion files to RM2 formatted files. Than we uploaded these files to Robovie R3 robot's computer. We played these files on physical robot. First performed gesture was "side" sign and it is shown in figure 4.3.

Figure 4.3: Transferred sign "side" performed both simulator and physical R3.

Later on, we checked the system with "forward", "up" signs. Physical robot played these signs, correctly and that motivated us to transfer complex 10 selected word which are used in previous example. We increased playing time to make signs slowly to prevent any accident. Robovie R3 demonstrated these words one by one. "Spring" sign can be seen in figure 4.4 while Robovie R3 performing.

Figure 4.4: Robovie R3 performing "spring" sign.

4.2.3 Results

We converted signs to RM2 file format and checked them on Roboviemaker2 before the transferring to physical robot. All signs performed on physical robot and several doctorate students who studies on sign language, verify the accuracy of the signs.

4.2.4 Discussions

Signs are saved as states of angles and during the simulation, interpolated data is added to pass one state to another. In simulator time, signs are showed slowly because of simulator timer. However, in real world time is faster, so created signs are performed faster than simulation environment. We need to expand step count between states of signs to see more feasible signs on real world.

4.3 Intelligibility of TSL Words on The Simulator

In this experiment we used a sign language game for advanced users to analyse the effect of virtual embodiment of R3 robot simulator on showing TSL words.

4.3.1 Research question and hypothesis

The research in this experiment was;

- The success of Robovie R3 Simulator in showing TSL words.

4.3.2 Participants and sample

There are 16 hearing impaired children (10 girls, 6 boys) of age 9-14 (average 13.5) with advanced level sign users and had severe hearing impairments. A few of them uses cochlear implant and can say a few words with oral speaking. In figure 4.5, one participant is shown while playing game on android tablet.

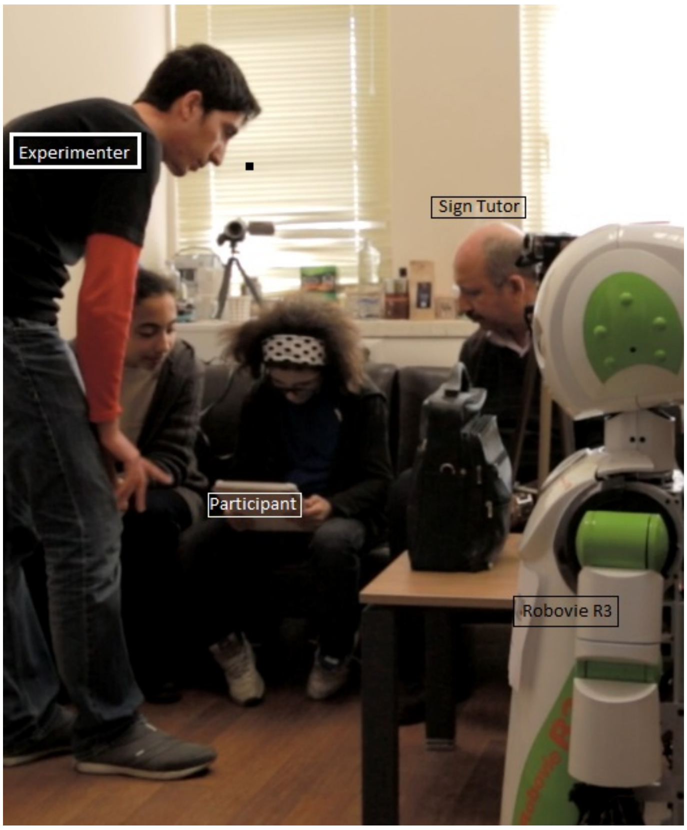

Figure 4.5: Participant playing game on android tablet.

4.3.3 Experiment setup

The experiment set up is similar with the previous study. In the game, first participant take a survey for demographic data such as name, age etc. Than 10 TSL words were asked with four choices. Most frequently used daily signs are selected and they are based on Turkish sign language dictionary [9]. The choices are three picture of signs choices and one pass option. Participants played game one by one and during the game we did not involved the process except taking demographic data. Several of them could not read questions such as name, age etc., so we expressed these questions with sign language and than they filled the survey. Game part was easy to figure out and they learned and played quickly.

4.3.4 Results

Nearly all of them have good results, average recognition rate of the participant is 75 percent, and this result proof that Robovie R3 simulator can be used as a tool to visualize TSL words and more motion before transferring data to physical Robovie R3 robot. Detailed result of the game is shown in figure 4.1.

Table 4.1: Results of Android Game.

Sign	Spring	To Throw	Table	Baby	Mount	Mother	Black	Big	I/Me	To come
Number Of Users	16	16	16	16	16	16	16	16	16	16
Correct	11	10	14	13	10	11	12	13	13	13
Wrong	5	5	2	2	6	5	4	2	1	1
Pass	0	1	0	1	0	0	0	1	2	2
Percent	68.75	62.5	87.5	81.25	62.5	68.75	75	81.25	81.25	81.25

In figure 4.6, you can see the correct rates of participants with simulator and physical R3 android games. Six participant with advanced sign language skills played game with physical R3 videos. Besides 16 other participants played game with R3 simulator videos, their results are nearly same. It shows simulator is as good as physical R3 to represent signs.

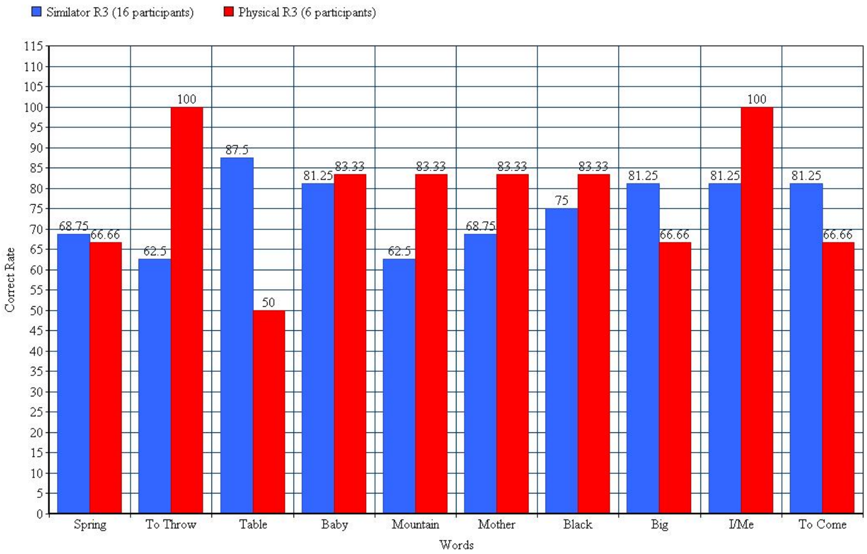

Figure 4.6: Correct rates of participants in the experiment with sign game.

4.3.5 Discussions

A few of participants push the choice more than once, so game skipped next question with the same answer. It was a leak of the game, but the others were more careful. In next studies, we will fix this bug of the game and have better results.

4.4 Capability Comparison of Mobile Embodiments of Nao H-25 and Robovie R3 on TSL

In this experiment, we want to compare Nao and R3 robots' performance on performing TSL words.

4.4.1 Research question and hypothesis

The research in this experiment was;

- Which robot platform is performing signs more similar to human tutor?

4.4.2 Participants and sample

There are 16 adults from computer engineering and related background. The participants are all male (average age of 28) and have neither prior sign language education nor experience. This game also tested with 5 primary school students (3 girls, 2 boys, age: 10.6). These children have no apriori sign language information.

4.4.3 Experiment setup

Sign language game for beginners is used in this experiment. Participants played game one by one. After filling the demographic data, in training part they learned 5 TSL words and give votes to the robots than they solved the test questions.

4.4.4 Results

The adult participants answered all questions true and mostly like R3's signing more than Nao robot. According to the post test surveys 63% of the adult participants preffered R3's signing more than Nao(37%). In table 4.2, adult participants answers and answer times are showed. In figure 4.7, also shows participants preferred signer Robot platform. Only one sign "Table", participants liked Nao's sign more than R3.

Table 4.2: Results of Sign Game for beginners with adults.

Signs	Correct Answers	Answer Time Average (sec)	Std
Mother	16	4.03	2.89
Spring	16	4.55	2.94
Big	16	6.0	3.61
Table	16	3.7	3.28
Black	16	7.51	3.59

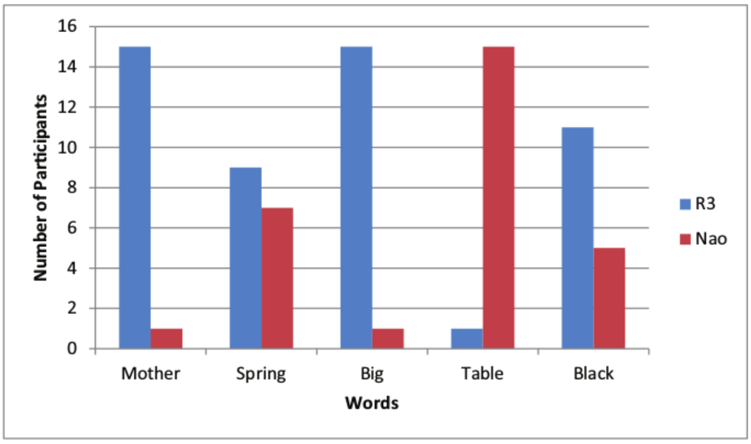

Figure 4.7: Choices of adults which robot signer is better on performing signs.

Children answered mostly correct, they also liked R3's signing most (64% R3, 36% Nao). Analysing in details, these children also liked Nao's signing of "Table" more than R3. Detailed answers and answer times of children is shown in table 4.3. Their choices for every word is also shown in figure 4.8.

Table 4.3: Results of Sign Game for beginners with children.

Signs	Correct Answers	Answer Time Average (sec)	Std
Mother	3	4.12	3.42
Spring	5	2.18	2.31
Big	4	5.47	3.14
Table	5	5.71	3.42
Black	5	6.50	4.29

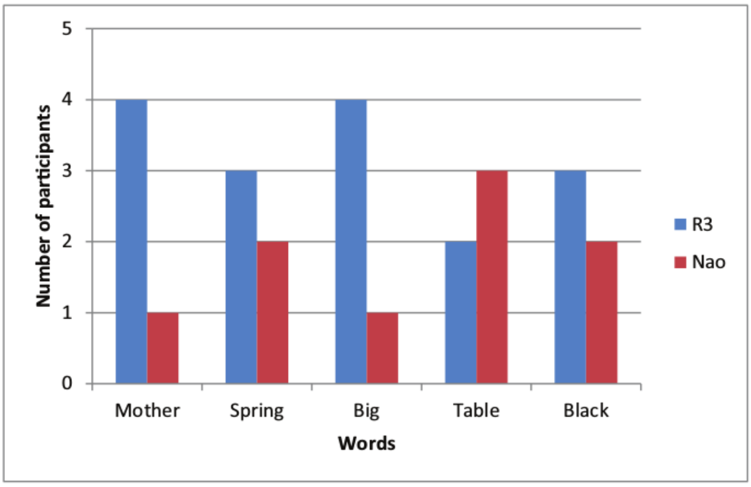

Figure 4.8: Choices of children which robot signer is better on performing signs.

4.4.5 Discussions

Participant mostly choose R3 as a better sign tutor except one word "table". R3 has five finger but Nao has only 3 finger, and in most sign words, fingers have an important role but table sign do not need individual fingers to perform signs. We assume because of the sign, they preferred Nao in this word.

5. CONCLUSIONS AND FUTURE WORK

This thesis set out a virtual embodiment which provide help to conduce TSL education with Robovie R3 robot. We will review the contributions of this thesis and discuss the future work.

Most robotic research concentrate on helping the children with communication problems such as hearing impaired or ASD. Turkish sign language is used to communicate with this children and researchers utilize robots to create interaction games using implementation of TSL words. It is a hard topic and without 3D embodiment simulators it can even cause unwilling damages on robots. Robovie R3 robot does not have a 3D simulator and in this thesis, we developed a Robovie R3 virtual embodiment as simulator and examine the quality of it using TSL signs. Our approach to measure the benefits of simulator is to perform TSL words on simulator and than transfer them to physical robot. Beside, we created an android based framework and ad interaction game application and analysed intelligibility of TSL words on simulator with testing them hearing impaired children who have advanced sign language skills. We also used this framework and implement a beginner game to compare different physical robot embodiments' performance. Our initial results reveal that creating signs on simulator and transferring them to physical robot is quite fast and accurate. It is also prevent unwilling damages on physical robot and provide a low cost training area for researchers.

5.1 Future Work

Robovie R3 simulator embodiment can be used to perform basic TSL words and show collisions to prevent damages on physical robot, but it can be improved to implement more complex actions. Physical Robovie R3 robot has five independent finger and it can move around with wheels. Gazebo simulator environment gives flexibility to add this features to Robovie R3 simulator. As a future work, we will add wheels, fingers and eyes to simulator, so more complex scenarios can be actualized on Robovie R3 simulator.

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