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Non-verbal Communication with a Social Robot Peer: Towards Robot Assisted Interactive Sign Language Tutoring

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Abstract—**This paper presents a humanoid robot assisted imitation based interactive game for Sign Language (SL) tutoring. The game is specially designed for children with communication impairments. The work presented is a part of Robot Sign Language Tutor[*] project. In this study, a Robovie R3 humanoid robot is used to express a set of chosen words in SL using hand movements, body and face gestures. The robot platform is specially modified with LEDs in face (for non-manual facial gestures), additional DoFs in wrist and 5 independent fingers at hands for robust SL generation. The robot is able to communicate with the participant by recognizing signs and colored flashcards through a RGB-D camera based system and generating a selected subset of signs, including motivating facial gestures, in return. The game also aims to improve children's imitation and turn-taking skills and to teach the words semantically. Current paper presents results from the preliminary study with a group of hearing impaired children, where children had almost 100% score in recognizing the robot's signs from a subset of 12 words.**

Keywords: Humanoid robots; interaction games; non-verbal communication; sign language.

I. INTRODUCTION

According to Piaget, in Preoperational stage (2 to 7 years) knowledge is represented by language, mental imagery, and symbolic thought [1]. Language development is strictly correlated with cognitive development especially in the early stages of human life. In case of communication problems such as hearing disabilities and autism spectrum disorder (ASD), sign language (SL) plays an important role as an alternative way of communication. Sign languages are visual languages composed by different sets and combinations of hand and upper-torso movements with various facial gestures. Learning sign language is of vital importance for hearing-impaired children from very early age, in order to interact with other individuals, and it also support their cognitive development [2]. The existing teaching materials are not adequate for children of early ages, 2-D sign language materials such as video based tools are hard to understand for this age group.

Language development in children offers a basis for several robotic studies. In [3] the language development in early stages of infant is used to enable the robot to communicate with people in natural language.

Likewise, robots can be employed as social peers for non-verbal communication as a part of therapy and education in case of verbal communication impairments. The study by Morasso, et.al. discusses the usage of humanoid robots as therapists [4]. The main features of a therapy robot are introduced as mechanical compliance, the capability of completing the desired movements and requiring minimum assistance while providing help, it should also provide adaptive assistance. In [5], the authors present a hypothesis on the usage of robots in rehabilitation which is expected to improve the therapeutic outcome.

One of the principle elements for children's intellectual development is the game playing. It contributes the children's development by improving their social and cognitive skills which are necessary to communicate with other individuals [6]. Vygotsky also highlights that playing a game is an important activity for children both for their development and creativity [7]. There are other researchers who put emphasis on play activity in the children development and socialization [8-10].

This study is a part of a novel research project "Robotic Sign Language Tutor". The main aim of this project is to design an assistive and social robotic system to be used with/by the human tutor/family as a part of the sign language education. The project focuses on using the assistive robot which can recognize children's actions and in return generate actions and feedback based on sign language within an interaction game scenario. We employ child-sized humanoid robots with high DOF in arms and fingers in sign language based interaction games [11-15].

The reminder of this paper is organized as follows: The relevant studies are summarized in Section II. The experimental setup and humanoid robot Robovie R3 are presented and the game design is detailed in Section III. The preliminary results are discussed in Section IV. Finally, Section V concludes the paper with future works.

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II. RELATED WORK

Designing a sign language tutoring system requires robust sign/gesture recognition to get feedback from the participants. Various studies have been carried out for gesture recognition for different sign languages. Either finger or hand gestures are used in these studies, tested with different cameras and different approaches [16]. HMM model-based systems are used with high success rates for American Sign Language (ASL) [17]. Braffort et. al, in their study on French Sign Language (LSF), tried to minimize prologue and epilogue gestures using coarticulation parameters [18]. The presented studies in [19, 20], focus on the recognition of the shape and the movements of hands, and on the facial gestures analysis to express different sign languages (TSL and ASL).

In addition to recognition, there are other sign language related studies, involving robots and HCI. In [21], several symbols of the Mexican Sign Language (MSL) alphabet are assigned to express specific tasks for the robotic system to carry out eight different tasks. The study in [22] presents a recent study on gestures and sign language in assisted living environments.

There are comparably few researches on the realization of sign language with robots because this requires a humanoid robot platform with two human-like hands. A robotic hand was developed in 1977 for spelling words using manual sign alphabet of ASL and different more sophisticated versions of these hands were developed for sign language realization in the last 30 years [23, 24]. However, hands are not enough to express 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 [25]. To express sign language successfully, child-sized humanoid robots with high DOF in arms and fingers are being used in sign language based interaction games [11-13]. There are also some avatar based studies to teach sign language, which are presented in [26, 27].

There are several successful user studies on non-gesture communication through imitation based interaction games with humanoid robots and human participants. The study in [28] implements the rock, paper, scissor game; and in [29] they describe a data collection experiment based on an interaction game inspired by "Simon says" where the turn taking was engaged by gaze direction, speech, and motion. On the other hand, in [30], an affective modeling methodology is presented which was tested with a robot-based basketball game. English Language tutoring with a humanoid robot assistant project [31] investigates child-robot interaction, and the idea of children's learning from robots. If the children had any previous English knowledge, they learnt much from the robot. This condition supports the idea in psychology literature that is common points and similarities ease the communication [31]. In 2012, a long-term experiment was carried out with Nao robot for analyzing children behavior, their involvement and entertainment [32]. The main aim of the work was to examine how children behave towards the robot. The study in [33] showed that having different roles in the human-robot interaction affects the engagement, and if the interaction was initiated by the robot, the participants were more willing for the interaction.

III. EXPERIMENTS

A. Robotic Platform Robovie R3

The robot used in the experiments is a specially modified version of Robovie 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, besides 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 an 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.

B. Research Questions

This study explores the impact of humanoid robots in teaching sign languages to children with verbal communication impairments.

The main research questions addressed in this study are:

- Does the robotic platform with expressive face and five fingered hands have a positive effect on the learning performance and motivation of participants, or their recognition ability of signs demonstrated by the robot?
- Will including the interaction games within sign language teaching process encourage the participants to participate, and improve their learning and recognition rate of the signs?
- Is there any significant difference on the learning or recognition performance of participants in case of physical versus virtual embodiment of the used robotic platform?

The study in [15] focused on the first two questions and verify the significant effect of the robotic platform with 5 fingers and the interaction games. This paper will focus on the effect of robot embodiment, mainly.

C. Experiment Setup

Two different experimental setups were used to perform the user studies. The first setup was designed to test the sign language "teaching" performance of the virtual robot. In this setup, the children were tested with a video of the R3 in large groups due to the space constraints. The tests were performed in the classroom of a collaborating high school of hearing-impaired children. The video of the Robovie R3 robot was projected to the standard projection screen (almost 90*120 cm) demonstrating and showing the different TSL signs in a pre-defined order. The children sat in front of the screen about 2-3 meters away from the screen and they watched 10 different signs from the video of R3. The duration of this introductory session was about 10 minutes. Since the children were already fluent in TSL, this session was sufficient to introduce the robot and the signs. In the second phase, the signs were given in a random order and the children filled the paper based test given to them. Due to the space and time constraints in this setup, the interaction had to be kept at minimum.

The second setup was designed to test the probable influence of the physical presence of the R3 robot. This setup was tested in a computer laboratory at Istanbul Technical University with smaller groups of participants. In this setup, the robot stands still during the tests, but extends its arms and uses its arms rapidly which might hit the people who stand in very close proximity. Therefore the participants are asked to sit to the chairs in front of the robot that are placed approximately 1.0 m away from the robot, and told not to touch the robot during operation. The experimental setup is displayed in Fig. 1. The presence of three experimenters in one session is ideal. One of the experimenters controls the RGB-D camera, while the second experimenter controls the robot and the third experimenter gives feedback to the robot and children with colored flash cards. The use of flash cards with cartoon like pictures allows the robot and the experimenter to communicate nonverbally with the hearing impaired children and to maintain the turn-taking and interaction within the game. Also a therapist with accurate sign language and verbal communication ability was present during the tests, to explain the experiment and to answer the children's questions about robot and environment.

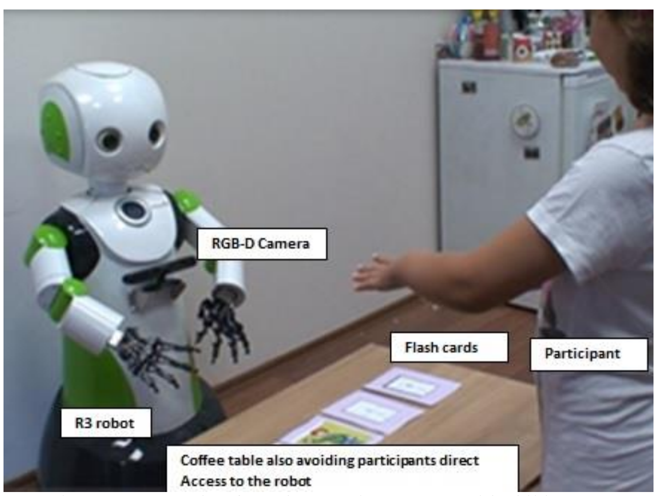

Fig. 1. A screen-shot from the experiment setup with children

D. Participants

The tests were performed totally with 28 (12 female, 16 male) volunteer participants; all of the test participants were hearing-impaired children who were fluent in Turkish Sign Language, and attending to the same collaborating high school for hearing impaired children. The children attending to both tests were selected by the collaborating sign language teachers of the same school among the students who were most fluent in TSL and willing to participate in the studies, and the children were accompanied by these sign language teachers during the studies. The first set of user studies with virtual robot were performed with 18 hearing-impaired students; 10 male students from the age range 11-16 years and 8 female students from the age range 12-15 years. The second set of the studies with the physical embodiment of the robot were performed with 10 hearing-impaired students; 6 male students (10-16 years old) and 4 female students (9-14 years old). The ages of the participants were distributed in the range 9 to 16 with the mean μ =13,11 years and standard deviation σ = 1,83.

E. Sample Set of Signs

In the experiments, a sample set consisting of 9 Turkish Sign Language (TSL) words was used for the training/demonstration phase. The signs were selected from TSL visual dictionary [35], this dictionary is composed of signs representing both abstract and concrete concepts. These words are selected from mostly used daily routine words of TSL that can be demonstrated by the robot without any physical or kinematical restriction. The accuracy and correct demonstration of the TSL words with the robot were verified by sign language tutors prior to the experiments.

The training set consisted of the signs "mother", "to throw", "spring", "mountain", "baby", "I/me", "big", "to come", "black". There was an additional set of signs consisting of 3 words meaning "robot", "car" and "hello". This smaller set of signs did not take place in the training sessions, only used in the tests together with the training set. The motivation is to test the recognition ability of the children when they encounter with robot expressing signs they haven't seen before on the robot. Here we had chosen simpler words with high iconicity.

In the experiments only 9 words from TSL were used due to avoid the boredom and fatigue effect on the children. When number of words and the duration of the tests are increased the participants can easily get distracted and tired and fail to follow the robot and the instructions, which decreases their motivation to play and success rates significantly [34].

F. Scenario

The proposed method combines computer vision module with the robot control module to handle imitation realization. The scenario has only visual clues. There are no verbal instructions instead of the instructions that are accompanied by the therapist in sign language, when necessary.

The motions of the Robovie R3 can be programmed via its visual based software Robovie Maker 2 (RM2). The developers can also implement the motions created by RM2 in another platform using its SDK programmed in C++. In this study, we used the motion created by RM2 and invoked them using its SDK to combine the robot's motions and the vision module in order to provide the necessary feedback to hearing-impaired children. The vision module uses different algorithms that are SURF feature detection, Bag-of-Words (BoW), K-means clustering and support vector machines (SVM) [36]. After the children showed colored cards to the robot, the image representations are obtained with Bow and SVM supervised learning started for classification. The SVM prediction initiates the pre-coded actions showing each sign.

We also have a sign recognition part to recognize the upper torso motions (signs) of human teacher we developed a RGB-D camera based system [36-37]. This sign/gesture recognition module is not employed here, instead the students are asked to generate the signs and these signs were recorded with a 2 Kinect system from front and side for off-line analysis and training of the system.

The game has three phases. The first phase is the introduction of the robot and its signing (demo/training phase). In this phase children participate to the experiment within a group composed by three people. Although some of the participants already know these signs, a familiarization session is performed for the participant to show them how the robot generates these signs (it is not 100% similar to human due to kinematic constraints). In this phase one of the experimenters or therapist explains the experiment to the participants and after a little demonstration, delivers 3 cards to each child. Every child shows the robot the 3 cards given to him/her and all 3 children see how the 9 signs are realized by the robot.

Then 2 children are asked to leave the room, and one child left in the room plays with the robot alone. We expect the active contribution of child in the game will make a positive impact on the child's both subjective and objective evaluation of the system. In this second stage, robot generates 3 signs (different from the cards shown by this child, but still from the same card set consisting of 9 cards), and the child is asked to show the relevant card to the robot, as seen in Fig. 2. If the card matches the sign then the robot smiles to the child. Else the robot shows a "neutral" face (straight mouth) and asks the next question. The failed or not answered questions are not repeated the robot continues with the next query. Once the child completes the given task, he/she leaves the room and another group member is taken for playing with the robot.

After the three children finishes playing with robot individually, they are taken to the room together, and this time the robot generates 12 signs of which 9 of them belong to the training set and 3 of them (the sign "car", "robot", or "hello") are not shown before to the children, and the children are asked to fill out a paper based test (Fig. 3) where the answers are represented with same icons on the flashcards. Previously we had tried to get a written test, but the writing performances of the hearing-impaired children are usually poor due to the differences of written spoken languages and sign languages. Therefore a visually instructed test is given in the third phase. To avoid children's cheating and being misled by other friends small groups are taken for test each time.

Fig. 2. A hearing-impaired child showing a flashcard to the robot in the second phase of the game

Fig. 3. Children filling the paper-based test in the final phase of the game in the presence of their teacher

IV. Preliminary Results and Discussions

In the previous studies; we tested different interaction game designs based on TSL through different test setups (classroom, and web based), and different robot platforms (virtual and physical) [11, 15]. In these studies, we used two different robot platforms, Nao H25 robot (3 dependent fingers in hands) and Robovie R3 robot. The participants had different profiles including university students, teenagers, and preschool children with typical hearing and hearing-impaired children from different age groups. In pilot studies conducted by Kose et al. in 2014 in collaboration with a school for hearing-impaired children, 29 hearing-impaired children were tested using Nao robot in a classroom based study [15]. In [38], an Android based multimodal mobile game is tested individually with similar group of children and adults. The games were also demonstrated in a primary school where 70 primary school children without any hearing disability took part in the studies [39].

In these studies, the scenarios focused on sign language imitation, turn-taking and visual feedback for teaching the semantics and generation (kinematics) of signs to the children. In the recent study, we focused on the recognition and understandability of the signs generated by the robot; therefore the children attending the study were selected from hearing-impaired children who had already mastered sign language. This study enabled us to test the accuracy of the signs performed by the robotic platform and elaborate our research considering the effect of physical presence and virtual presence of the R3 robot.

The demonstration performance of the robot in both setup and the recognition ability of the participants were evaluated in terms of recognition rates for each sign and the general score that each participant got from the paper-based test filled by the participants. The recognition rate for each sign was calculated as the ratio of the total number of times the sign was correctly recognized by the participants to the total number of times that the sign was queried by the robot. The general score for each participant was calculated as the ratio of the number of signs correctly recognized by the participant (number of correctly answered questions) to the total number of signs (total number of test questions).

The preliminary results showed that most of the signs were recognized correctly when they were demonstrated by the robot with physical embodiment. The recognition rates for each signs demonstrated by physical and virtual R3 robot are displayed in Fig. 4. The sign meaning “to come” which was part of the training set was not taken into consideration because during the paper-based test session the children had difficulty to match the selected icon to represent this verb with its semantic meaning even though they didn’t have any difficulty to recognize the demonstrated sign during one-to-one interaction sessions.

Apart from the 8 common signs demonstrated in the training session, the other signs which were not demonstrated but queried by the robot had also high recognition rates except the sign meaning “robot” which had 40% rate of recognition. The signs meaning “car” and “hello” had recognition rates of 100% and 90% respectively. This apparent difference in the recognition rates of these signs may be explained by the unfamiliarity of the children with the word “robot”. And also the signs meaning “car” and “hello” had accurate iconic representations which helped the children to distinguish the semantic meaning of these signs.

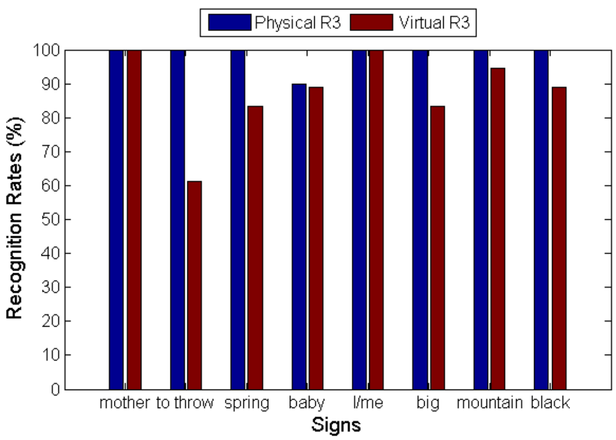

Fig. 4. The selected TSL signs and the recognition rate of hearing-impaired participants

Inspired by the idea that the recognition rates of the signs demonstrated by the virtual robot seem to be slightly lower compared to recognition rates for the signs demonstrated by the physical robot; a one way ANOVA test was performed on the recognition rates of the 8 common signs to see the influence of the physical presence of the R3 robot. The test showed that the physical presence of the robot had a significant effect on the recognition ability of the hearing-impaired children who were fluent in TSL ($F(1,14) = 5.99$, $p = 0.028$ with $p < 0.05$).

The general scores of the children were also computed and compared with respect to the scenarios with physical or virtual embodiment of the Robovie R3. The mean test score of 10 participants in the physical presence of R3 were 93% and the mean score of 18 participants tested with the video of R3 was 89%. Although the mean test score with physical embodiment of the R3 robot seemed to be higher; another one way ANOVA test was performed to see the significance and examine the influence of the physical presence of the robot on the general scores; the result had shown that it also had a significant effect on the recognition and success of the participants with prior TSL knowledge ($F(1,26) = 4.684$, $p = 0.039$ with $p < 0.05$).

A one way ANOVA test was performed to see the gender influence on the general test scores. The result showed that the gender of the participants didn’t have any significant effect on the test scores ($F(1,26) = 0.146$, $p = 0.705$). And also a 2x2 ANOVA test were performed to see if the embodiment of the robot (physical vs. virtual) or the gender of participant (female vs. male) had any combined effect on the recognition rates of the 8 signs tested with both setup. These results supported the one-way ANOVA test results and showed that the difference of embodiment had a significant effect ($F(1,28) = 6.96$, $p = 0.013$ with $p < 0.05$) but the gender of the participant did not cause any significant difference on the sampled recognition rates ($F(1,28) = 0.1$, $p = 0.758$). Apart from supporting the previous one-way ANOVA tests, the results of the 2*2 ANOVA indicated that there wasn’t any combined (interaction) effect of the two factors (physical vs. virtual embodiment and female vs. male) on the recognition rates ($F(1,32) = 1.18$, $p = 0.286$).

Overall, the preliminary results are encouraging in terms of the humanoid robot’s contribution in the sign language learning and reinforcement process of individuals with different profiles. The results emphasize that the presented interaction game can be played with children who suffer from different degrees of hearing impairment and the humanoid robots may be presented as an effective assistive teaching material in the context of improving the interaction ability of the children. The results also show that the physical embodiment of the robot has an important contribution in the “sign teaching” task of the humanoid robot and the performance and engagement of the children improve with its presence.

V. Conclusions & Future Work

This study has been carried out as part of an on-going research which aims to assist sign language tutors in teaching sign language to children without any prior knowledge or reinforce the vocabulary of children who are fluent in sign language through interaction games played with a humanoid robot.

In this study, a nonverbal interaction game is proposed and tested with hearing-impaired children to verify the ability of a humanoid robot with 5 fingers and expressive face in generating recognizable signs from TSL. Each child found the chance to interact with the robot individually and communicate with it via colored cards and signs. A paper based post-test was used to verify the children’s recognition of robot’s gestures. The variance analysis tests also verified that the robot embodiment had a significant effect on the recognition ability of the children who were fluent in TSL, compared to the video based study with the similar group of children and video recordings of the robot, tests with the physical robot improved the children’s recognition of signs and encourage them to play more with the robot. Participants both played with robot as a team and had chance for one-to-one interaction with the robot which increased their motivation and concentration in the game. Participants had also remarked that Robovie R3 had produced smooth and natural-looking gestures.

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.

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