Facilitating a preparatory stage of real-world experiments in a humanoid robot assisted English language teaching using Gazebo simulator

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Abstract **— A simulator is a software application that allows imitating an experimental environment and controlling a process or an instrument. Projects in human-robot interaction (HRI) field face different challenges during real world experiments, which include improper robot behavior, mistakes in an algorithm logic, software and hardware failures, and generic lay participants on a user side. Simulators could help to avoid a number of problems that researchers would definitely face within real world experiments at algorithms' testing stage. This study presents an experimental validation in Gazebo simulator and real-world experiments for English language lessons scenarios with a small size humanoid Robotis DARwin OP2. We investigated advantages of using Gazebo simulator in constructing modular generic HRI blocks and global HRI scenarios in order to optimize a humanoid robot assisted process of studying English. The simulator saved a significant amount of efforts and time at preparatory stages, allowing robot programmers and HRI developers to obtain a quick feedback from users and their requirements for necessary adjustments.**

Keywords — modeling, simulation, human-robot interaction, humanoid

I. Introduction

Social robotics is one of the fast developing interdisciplinary areas nowadays. Development of social robotic platforms requires joint efforts of specialists in various fields, including human sciences experts that with sociocultural problems. Some authors require a social robot to behave like a person and to demonstrate a clear presence of intelligence so that the robot could perceive and respond to its current social environment [1]. The main difference between an industrial robot and a social robot, in addition to their ISO definitions that consider an intended use, is that the later one is originally designed to interact with a human. Social robot types might significantly differ in their design, construction, cost and applications, which include office and entertainment robots, medical and therapy robots, wearable devices and robotic assistants [2]. These robots should play a crucial role in communicating with humans [3]. A great number of studies investigate different aspects of human-robot interactions, and one of such interactions is employing robots within an educational process. Among the main obstacles for using robots in daily educational processes is an amount of time that should be spent for learning optimal robot behavior that would correspond to a particular situation and intended learning achievements because real HRI trials are slow and costly both in a sense of time and required efforts. To solve this problem researches attempt to involve simulations of a real world environment and HRI scenarios. A usage of a virtually simulated robot helps to solve a problem of a program testing in a virtual environment before it will be launched on a real robot. This could help avoiding at least some of possible software and hardware failures. A simulation in HRI requires to model robots in all their complexity as well as a mean of representing and interacting with human agents [4]. The main problem researchers face while constructing a computer simulation is achieving a suitable level of correspondence between virtual processes within the simulator and their real world counterparts, i.e. those processes that need to be simulated. For this reason, a simulation of a robot in a virtual space requires a proper theoretical base that formulates all necessary requirements for locomotion, manipulator and interaction operations at preparatory stages while testing the virtual robot behavior before transferring developed algorithms onto a real robot. Simulators allow modelling physical processes and conducting experiments virtually without any tools and real hardware, which makes their use significantly safer.

A broad variety of open source simulation environments are used in robotics field, and software that is used for HRI simulation is rather diverse. Literature review showed that many researchers often use such robot simulators as Gazebo (e.g., for rescue robotics [5, 6] or medical applications [7]), USARSim [8] (for urban search and rescue robotics or HRI), MORSE [4] or WEBOTS [9]. In our work we used Gazebo simulation for educational lessons simulation. Many research works on ROS and Gazebo based robot simulations [10, 11, 12] allow to conclude that Gazebo is a practical and reliable open-source 3D robotics simulator. It has an open source code, provides realistic rendering of environments and has several advantages over other robotic simulators, which made it rather popular in the global robotics community. Moreover, Gazebo simulator merges with the Robot Operating System (ROS) software platform, i.e., a program that is developed in the ROS-based simulator for managing a virtual robot could be easy to transfer onto a real robot.

The main goal of the paper is to examine benefits of Gazebo simulation that was designed to help in effective lessons planning with a humanoid robot. Our hypothesis was that with a successfully completed training with a ROS-based virtual robot at a preparatory stage, the resulting strategy could be easily transferred to a real ROS-based robot with significantly less efforts comparing to an approach when the real robot is directly programmed and next all tests, algorithm and code adjustments, and validation experiments are performed with the real robot.

The rest of the paper is organized as follows. The next section describes Gazebo and ROS. Section 3 describes the problem and its solution. Section 4 explains the simulation, field experiments, and results. Section 5 concludes the paper.

II. Related work

Literature review showed that many robot simulators with different features became quite popular among robotics researchers within the fields of medicine, for example, for minimally invasive surgery [12], USAR tasks [6], path planning [13] and many others tasks. A number of works presented simulators (e.g., Gazebo, Webots, etc.) using Open Dynamics Engine (ODE) for realistic movements. In [11] the authors presented basic principles of working with Gazebo, its architecture and applicability for processes' development for real world robots. Farchy et al. [14] used SimSpark simulator, developed by the RoboCup initiative. SimSpark also uses ODE to simulate rigid body dynamics. They set an aim to utilize parameters optimized in simulation in order to improve a robot's task performance in the real world. As a methodology, the authors introduced an optimization framework Grounded Simulation Learning algorithm that implies behavior testing on a real robot and compared to expected results from the simulation. The authors used a machine-learning approach to bring the simulated results closer to the reality.

Study [4] presented five independent applications of MORSE simulator in the field of HRI. It was mentioned how simulation in HRI have to address in parallel constraints stemming from robotic simulation and virtual agent simulation, while remaining a lightweight easy-to-use tool. The paper claimed that simulation is useful to carry out experiments in HRI, and allow for quick adjustments in interaction scenarios. A number of studies described experiments that were conducted in USARsim, e.g., Wang et.al. [15] introduced the USARsim high-fidelity simulation and discussed an importance of validation of simulations for HRI while the simulator usage was described through experiments in camera control for remote overview and integrated display of orientation information.

In multiple works on real-world experiments for HRI authors described different issues, which they had faced during experimental trials. For example, Kanda et.al. [16] conducted experiments with an interactive robot Robovie that was created for HRI in shopping malls. Robovie prompted a right way and provided some useful information about a mall to visitors. Researchers developed a face-tracking algorithm integrating information for an interactive robot that controls the robot's head orientation. However, a number of unforeseen situations in the algorithm logic occurred, e.g., the authors reported on person tracking and identification problems due to false-positive face detection. To overcome the real-world difficulties researches adopted a network-robot-system approach, where a lack of some robot's capabilities was supplemented by ubiquitous sensors and a human teleoperator on-demand support. Koizumi et.al. [17] and Lier and Wachsmuth [18] also reported difficulties that were related to a robot usability, interaction and perceptual components such as speech recognition, estimation of humans' position, visual detection, and identification of users, which appeared during field trials for a teleoperated communication robot.

The extensive literature analysis helped us to select a proper simulation tool and to draw up scripts for robot assisted lessons taking into account typical for humanoid robots features and issues. We selected Gazebo open-source 3D robotics simulator for a number of reasons. Firstly, Gazebo integrates perfectly with ROS framework. Secondly, it allows to safely move from testing algorithms in a simulation to testing with a real robot. DARwin OP2 robot that was used for our experiments within this project has an open source code package for working in Gazebo. The main programming language of the simulator is C++, which allows code reuse and is very efficient for robotics applications in general.

III. Solution

The main purpose of this study was to identify the benefits and necessity of experiments' simulation at a preparatory stage in order to improve and facilitate further the process of learning languages using Robotis DARwin OP2 real small-size humanoid robot. The experiment methodology included the following main steps:

- development of a program of the experiment;

- evaluation of measurements and selection of means for the experiment;
- conducting the experiment;
- processing and analysis of experimental data.

Previously we had carried out a set of pilot field trials without simulation in a natural setting of a kindergarten [19]. We had developed a program of experiments, which implies different types of research methods: experiments in a simulator, laboratory and field experiments. In our study we had integrated robotic technologies into the process of teaching pre-school children vocabulary of English language. An integrated experimental methodology based on an interdisciplinary approach had included interaction of a teacher, a robot and a child followed be a set of subsequent interviews with the teacher and parents of the children. In the real world experiment, we had used a humanoid robot DARwin OP2, which had interacted with the children according to developed by us behavioral scenarios. The data analysis was based on video materials, questionnaires results, interviews, and researchers' observations during the experiments.

For the research presented in this paper the simulation was carried out using ROS / Gazebo. To demonstrate how the simulation could support a research in HRI, we developed new HRI scenarios scripts that included six English language lessons with one lesson being a non-learning lesson (so-called Robot introduction lesson) for laboratory experiments. We developed a motion library for DARwin OP2 humanoid robot, which represents a number of modules for each movement. A limited selection of examples of such modules is presented in Table 1. This library was used for various movements, for example, "raise two hands up", "close your eyes" and "raise your left hand 45 degrees", etc. Such modules were used in order to supplement verbal communication of the robot with the children (using a certain replica from the HRI scenario script) with non-verbal actions (i.e., motion).

TABLE I. Modules

Name	Action at a run time
Clap	Robot claps hands over the head
close_eyes	Robot closes eyes with both hands
open_eyes	Robot open eyes
hand_45_front_both	Robot extends both arms in the front at 45 degrees (points to something)
hand_45_left	Robot extends the left arm the front at 45 degrees (points to something)
hand_45_right	Robot extends the right arm the front at 45 degrees (points to something)

To reproduce a movement, we execute a command, the input of which is a name of a module. For example, if the robot says "Good morning, children, how are you?", then "hello_left_arm" module should be executed, followed by "front_both_arm_45" module, which means "robot waves the left hand" and "robot extends two arms in the front at 45 degrees," respectively.

In each scenario (Table 2) replicas of the robot were divided into small subsets, and certain movements were selected for execution together with each replica, i.e., each replica was synchronized with a specific movement. To invoke a replica and a movement at the same time, the name of the desired module is passed as an input argument to a calling function, which reproduces the replica and its corresponding movements simultaneously. Lessons scripts contain vocabulary and word combinations on the topics of seasons, colors, domestic animals, fruits, and forest animals.

TABLE II. A part of a lesson script

Stages	Teacher (T) / Robot (R)	Children actions (assumed)
I stage. Organizing stage– 2 min.	**T:** Hello, children! I'm glad to see you. Today Darwin came to visit us again. Darwin, say hello to the kids. **R:** Good morning, children, how are you? **S2.L1.replica1.txt** (with "hi_left" and "hand_45_front_both" modules) **T:** This is our third lesson today, where Darwin will help us to learn the names of domestic animals.	Hello! Good morning, Darwin! Good.
II stage. Setting the goal of the lesson. Improving vocabulary skills – 6 min	**T:** (The teacher knocks on the table imperceptibly) *Says in Russian: "Who is that knocking there? Darwin invited pets today. But they are afraid to come in, let's call them. We should say"* - in English: "Come here!" and name the animal, then it will come. In Russian: "Darwin, call you first". **R:** Dog, come here! **S2.L1.replica2.txt** (with "hand_45_left" module) **T:** The teacher takes out a toy dog from the bag and says: "Repeat after Darwin – Dog". *In Russian: "I will get toys of domestic animals from the bag which Darwin will call and you should repeat after Darwin".* **R:** Cat Sheep Cow Horse Hen **S2.L1.replica3.txt** (with "hand_45_left" module)	Repeat words after the Robot

Next, we analyze the third lesson scenario “Domestic animals” in more details. The time of the lesson is 20 minutes. The objective is to learn new words: a dog, a cat, a sheep, a cow, a horse, and a hen. The first phase of the lesson is a preparatory one: a teacher motivates children to learn new vocabulary, while the role of the humanoid is to assist the teacher. The lesson starts with the teacher’s words: “Hello, everybody! Let's begin our English lesson”. Then the teacher asks: “Guys, look who is our guest today?”, the kids respond (presumably, since within each scenario we could only assume children behavior, while for the robot and for the teacher each phrase is well-prepared in advance), and the teacher says: “Yes, it is DARwin (a short name we gave to the robot to create a friendly atmosphere), say hello to him!”. DARwin OP2 greets the children: “Hello, kids! Glad to see you. Tell me please what season is it now?” (The question about season is a reference to the first lesson).

While saying a replica the robot performs particular movements: waves its hand ("hi_left" module) and extends its hands forward, pointing at the children ("hand_45_front_both" module). After that the actual lesson starts. In this stage the children should be active; the teacher uses illustrations, explanation, demonstration, etc. for memorizing new vocabulary. The teacher introduces a theme of the lesson, “Domestic animals”, and with the help of DARwin OP2 the kids learn new words. The humanoid pronounces the names of animals and points at a picture of a corresponding animal, raising left arm in front of itself at 45 degrees ("hand_45_left" module). After learning new words, the kids do a physical activity break when they repeat basic exercises after DARwin OP2. The robot verbally explains and demonstrated each exercise. For example, “Stand up, sit down” (“stand_up” and “sit_down” module), “Clap, clap, clap” (“clap” module), “Point to the window” (“hand_90_right” module), “Point to the door” (“hand_90_left” module), “Point to the floor” (“hand_down_left” module), etc. Further, the robot plays a game with the children, named “What is missing”. The robot says “Close your eyes” and while pronouncing this phrase it closes its eyes too, using “close_eyes” module. The teacher removes a single animal from the set of all animals, the robot prompts the kids to open their eyes (“open_eyes” module) and asks what is missing (with “hand_45_front_both” module), lifting its arms in dismay if the children answer correctly and praising them with “Good job” (“well_done” module). After the game, the teacher sums up the entire lesson and asks children to say goodbye to the robot. The humanoid, in turn, says goodbye to the children and waves its arm (“hi_both” module).

It is worth clarifying why the teacher says some phrases in Russian (emphasized with italic text in Table II). Firstly, the scenarios followed an existing kindergarten’s teacher methodology. Secondly, while according to the latest communicative methodology it is highly recommended to use exclusively English, this is not appropriate in a nursery school that is not a specialized English school (our case) and the children do not have sufficient knowledge yet in order to manage all communications solely in English. The native language in this case serves as a proper teaching tool.

A. Real world experiments

For our experiments we used DARwin OP2 robot [20] (Fig. 1) made by South Korean company Robotis. It is a humanoid robot with an open source architecture based on the Linux operating system. Robotis OP2 is able to play audio, perform onboard calculations of medium complexity, store limited amount of information between sessions, and has Internet connection. The latter allows researchers construct HRI scenarios using existing text-to-speech (TTS) applications, which might require a continuous Internet connection.

In our previous work we had developed detailed scenarios of five English lessons for children aged 5-6 years. We took into account rapid fatigue of pupils, therefore each lesson lasted only 15-20 minutes. The five English classes were held within a period of two weeks. Each lesson was divided into a set of phrases and actions. A separate voice file was created for each replica in order to remove continuous Internet connection requirement; the replicas correlated with the movement of the robot.

Fig. 1 – DARwin OP2 robotic assistant

In our real world experiments that were carried out in the kindergarten [19], a human operator controlled a robot in a teleoperational mode, sitting behind a screen so that children could not see her. During the classes, the robotic assistant stood on a table in front of the children because of the robot’s small height, which allowed a better information perceiving by the children (Fig. 2).

The scripts for each lesson were designed in a way to facilitate the greatest children’s interest. The kids with the help of the teacher and the robot learned a new vocabulary; the study of words took place through games and songs. Each time after a new lesson, we conducted a survey on the topics covered. In each scenario there were three main characters - a teacher, a robot, and children. All phrases of the robot were pre-recorded, and the teleoperator could select a most appropriate answer of the robot in a real time. However, even though the teacher was well acquainted with the scripts, participated in their development and validation (testing), unforeseen situations still occurred as we did not take into account some important factors. For example, while running the scenarios in the kindergarten we faced issues with vocal and locomotion characteristics of a robot, and avoiding of these problems should facilitate to better educational process. Yet, most of these problems could be predicted in advance and fixed at the preparatory stage within the simulator. There were also problems with children speech recognition because of the inconvenient position of the teleoperator.

Fig. 2 – Robot position during the lessons

B. *Virtual experiments*

We created a ROS-node to reproduce movements from the library. The node calls a particular module, which in turn contains a joint angle position in radians for each joint of the robot and transduces these values into robot actuators motion. In the simulation we placed the virtual robot on a horizontal surface of a table to simulate the exact pose of the robot during real-world experiments (Fig 3 to correspond with Fig. 4).

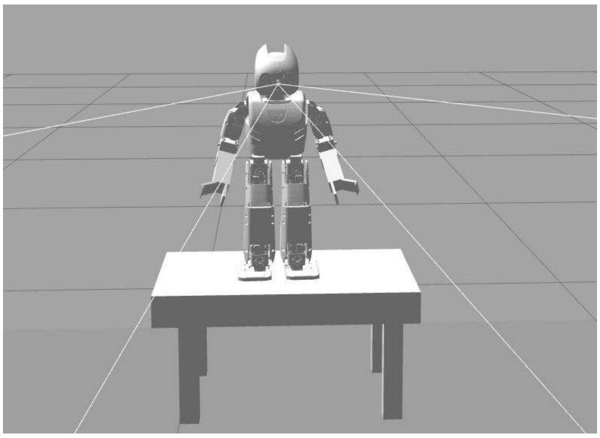

Fig. 3 – Robot position in Gazebo environment

The process of preparing to real world experiments via virtual experiments in the Gazebo was conducted according to the following steps:

- selecting a phrase from the lesson's script;
- creating a set of (a movement and a corresponding verbal phrase) modules that corresponds to the phrase;
- running the module in Gazebo simulator;
- video recording of the run;
- verification of the obtained virtual robot behavior against the predefined script of the scenario;
- discussing of the discovered problems and required adjustments to vocal or motion issues, or their synchronization; the algorithm developer, the robot programmer and the English language teacher as well as independent observers (volunteers among laboratory staff) were involved at this step;
- adjustments in algorithms and code;
- repeating the process until a successful correspondence between the virtual robot behavior and the script is achieved and proceeding to a next replica.

Fig. 4 – Robot position during the real-world experiments

After movements were successfully tested in the simulator we transferred them to the real robot. For experiments in the laboratory environment only minor adjustments in the radiant values of joints were required for the virtual scenarios (and code) in order to compensate for real world features of friction and motor imprecision at certain joints' movements. In total, these adjustments for real world features took us about 5 percent of the total time that was spent at preparatory stage while moving from a lesson's script to its implementation on the real robot. Since DARwin OP2 acted as a teacher assistant, it needed to communicate with children, and replica files were created for each lesson. Then the scripts were tested with a speech that was synchronized with movements.

IV. Conclusions and Future Work

In this study we confirmed the importance of using simulators in the field of HRI at a preparatory stage. Since physical real world experiments are rather expensive and time consuming, it is much more convenient to conduct them in a simulator firstly. After the virtual and real-world testing experiments we identified a number of important benefits in using the Gazebo simulator at the preparatory stage. Firstly, the simulator was convenient in use and it was especially useful for a teamwork during COVID - 19 pandemic quarantine when our team could not meet daily at the university laboratory and had a limited access to the real robot. Secondly, the functionality of the simulator allowed creating any required virtual world and imitate real experiments that could be transferred onto a real robot with a minimal effort. Finally, we observed a significant speed up of a preparatory stage since we did not have to take care of hardware issues until the moment when all algorithmic and software developments were successfully verified against the desired HRI scenarios.

Next, we plan to delve deeper into researching a way to use simulations at a preparatory stage of HRI experiments and to consider various software and hardware issues that could be predicted and spotted at the preparatory stage and thus prevent major failures at a time of real world experiments. We would like to extend the current results to HRI for urban search and rescue (USAR) applications within our future work.

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