An Integrated System to approach the Programming of Humanoid Robotics

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Abstract. This paper describes a set of laboratory experiences focused on humanoid robots offered at the University of Padua. Instructors developed an integrated system through which students can work with robots. The aim is to improve the educational experience introducing a new learning tool, namely a humanoid robot, and the Robots Operating System (ROS) in a constructivist framework. This approach to robotics teaching lets students exploiting up-to-date robotic technologies and to deal with multidisciplinary problems, applying a scientific approach. By using humanoid robots, students are able to compare human movements to robot motion. The comparison brings out human/robot similarities, pushing students to solve complex motion problems in a more natural way while discovering robot limitations. In this paper, the learning objectives of the project, and the tools used by the students are presented. A set of evaluation results are provided in order to validate the authors' purpose. Finally, a discussion about designed experiences and possible future improvements is reported, hoping to encourage further spread of educational robotics in schools at all levels.

Keywords: Simulation, Humanoid Robots, Teaching Robotics, ROS, Gazebo, Robovie-X

1 Introduction

Educational Technologies (ETs), meant as the set of practices designed to enhance the learning activities, can be used as means for didactic activities in different specific contexts. In particular, Educational Robotics (ER) adapts students to current technologies, where the Automation Technology (which is related to the use of mechanical, electronic and computer-bases, in the operation and control of the autonomous systems) plays a very important role. Robotics involves several fields from computer vision to motion planning, from humanoids to manipulators and wheeled robots.

There are three main methods that can be adopted to teach a discipline: behaviorist, cognitive, and constructivist. We decided to follow the constructivist approach because of several advantages attested in different psychological

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 93-100

studies [4]. Constructivism is a theory about teaching and learning with roots in education, sociology, philosophy and psychology. The main idea is thinking that human learning is constructed: a self-regulated process of resolving inner cognitive conflicts that often become apparent through concrete experience, collaborative discourse and reflection [3]. Learners build new knowledge upon the foundation of previous one. This view of learning assumes that knowledge is an individual construction which corresponds to physical world. In this sense, student experimentations play a key role during the teaching process. So, student centered learning activities which encourage multiple representations of concepts and relations are suitable to handle the different experiences to advance to a better level of understanding. In this way, students should apply their current knowledge in new situations in order to verify their intuitions and discover if what they suppose is valid or not using a scientific approach [6]. Based on the Papert's perspective of Constructivism [1], and according to [13], a great number of robotic lectures and experimental laboratories have been introduced in classrooms of all levels of education. In Greece, Italy, Spain, France, Romania, Czech Republic the TERCoP project [2] introduced ER in primary and secondary schools [8]; the Engineering Department of the University of Padua, Italy, offers advanced laboratory experiences also to Master level students.

This paper describes the set of laboratory experiences on humanoid robots offered during the "Autonomous Robotics" (AR) course of the Master of Science (MSc) in Computer Science of the University of Padua at the Intelligent Autonomous Systems Laboratory (IAS-Lab) in the academic years 2011/2012 and 2012/2013. Instructors developed an integrated system to provide students the basic tools necessary to work with humanoid robots. It consists of a real and virtual humanoid robot, the Vstone Robovie-X [16], a simulation environment, Gazebo [5] and a robotic framework, ROS [15], equipped with the robot motion libraries and taught to provide the basis to create a development environment suitable for first step robotics users. Students are asked to solve some motion planning problems both with simulated and real platform. The goal is to make students capable to control a robot with many Degrees-Of-Freedom (DoFs).

Only few robotics courses adopt real humanoid robots in laboratory experiences. Their high cost, the efforts required to maintain their proper functioning, and the necessity to provide software packages that allow unqualified users to interface with them discourage their use as educational tools. The proposed system, instead, aims at highlighting advantages offered by these complex robotics platforms: increasing the students experience and knowledge. They will be able, for example, to compare human movements with the humanoid motion, to solve complex problems like the stability check of the robot and the resolution of complex inverse kinematics problems. Other types of robots, like the wheeled ones, do not offer these features.

The rest of the paper is organized as follows: in Section 2 the robotic course is described, together with the expertise that it aims to offer to students. In Section 3 the laboratories experiences are summarized focusing on the skills that they intend to transmit to students. Also a brief description of the integrated system

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pp. 93-100

developed and the main instruments used is provided. Section 4 contains an evaluation of the proposed approach, based on students feedback. In Section 5, some conclusions and future perspectives are discussed.

2 The course

"Autonomous Robotics" (AR) is a second year course of the Master of Science (MSc) in "Computer Science" at the Faculty of Engineering of the University of Padua (Italy). It intents to offer students methodological bases for programming autonomous robotics systems. It provides a mixture of theoretical class lectures and practical laboratory experiences. The former aim at building a strong background on robotics fundamentals, perception systems, computer vision, and navigation; the latter lets students acquiring skills on using software tools and algorithms exploited in robotics.

Students have to deal with five laboratory experiences, solving increasing difficulty problems. As presented in [9], students begin by using simple platforms (LEGO Mindstorms [7]), and gradually improve their skills coming to the end of the course by using more complex robots (VStone Robovie-X [16]). This approach confirms the constructivist line at the base of the course: it leads to an individual construction of the knowledge, because students by their own, find the better method to solve proposed problems acquiring the capability of adapting learned techniques to real robotic platforms.

3 Laboratory experiences

In the following, the set of laboratory experiences focused on humanoids proposed in the course will be described. They involve some basic challenges regarding humanoid robotics: robot control with high number of degrees-of-freedom, stabilization, and perception through sensory information. The robot motion is compared with human motion acquired by means of a RGB-D sensor: this way is possible to better find the differences between the two motion systems. Despite human movement and humanoid robot one seem to be very similar from a naive point of view, they differ considerably.

3.1 The framework: ROS

Robot Operating System (ROS) [15] is an open-source, meta-operating system that provides services usually expected from an operating system, including hardware abstraction, low-level device control, message-passing between processes, package management, tools and libraries useful for typical robotics applications, such as navigation, motion planning, image and 3D data processing. The primary goal of ROS is to support code reuse in robotics research and development and, in this direction, is designed to be as thin as possible and its

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pp. 93-100

Fig. 1. The small humanoid used in this work: the Vstone Robovie-X.

libraries are ROS-agnostic and have clean functional interfaces. Among all available frameworks, ROS has been chosen since it supports Object Oriented Programming (OOP), and also because its community is very active, and represents a valuable help. A large variety of tutorials are available from which students can easily learn. In particular, the Fuerte (2011/2012) and Hydro (2012/2013) releases have been used from the students to develop their software. The effectiveness of ROS in teaching is demonstrated by a large number of robotics courses which adopted it, including Brown University (USA), Cornell University (USA), University of Birmingham (UK) and Stanford University (USA). The choice of employing ROS for teaching robotics is important to let the students have experience of a complete and modern software framework for robotics.

3.2 The humanoid: Robovie-X

During previous experiences in the same course [9], students have the possibility to work with a mobile platform: the LEGO Mindstorms. Using ROS enable them to easily handle a different robot in the experiences described in this paper. The robot adopted is a small humanoid developed by Vstone: the Robovie-X. It combines high motion performances with accessibility, with seventeen degrees of freedom (1 for the head, 6 for the arms and 10 for the legs) and the VS-S092J servos having 9.2 kg/cm of torque. These features make it capable of fast walking, dancing, flip, side-flip, standing-up, playing soccer and many other activities. It is a small, light, and relatively inexpensive platform with its 1.3 kg of weight and 343x180x71mm (HxWxD) of dimensions that makes it handy and easy to carry.

3.3 The virtual environment: RViz and Gazebo

A virtual model of the robot is also provided to the students to get it visualized in RViz [11] or simulated in Gazebo [5]. RViz is the 3D visualization environment for robotics coming with ROS, Gazebo is one of the most complete open source 3D simulators. Both of them are necessary to figure out the robot reactions to the developed algorithms before testing them on real equipment.

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pp. 93-100

3.4 Experience 1: Motion remapping

In the first experience, students have to develop a teleoperation mapping between human and robot. The human motion has been acquired by using a RGB-D sensor and a skeletal tracking system, namely NiTE [14]. An open-source ROS package [10] has also been developed to extract skeleton information and to track them as a tree of multiple coordinate frames referred to the human joints over time. Student used this standard ROS structure, called *tf* [12], in order to generate a robot motion as similar as possible to the human movements.

Robotics objectives: The main goal is to make students familiar with humanoid robots and their motion. They should analyzing the movements performed by a human actor and subsequently transposing them to the robot DOFs dealing with the differences between the two complex motion systems. During this experience, students work with some advanced ROS modules. In particular, they familiarize with the transformations and frames (*tf*) package and with different reference systems in order to learn how to change from one to another while maintaining the fundamental rototranslation constraints. Once students are familiar with these concepts, they are asked to evaluate robot characteristics in both virtual and real environment in order to obtain a good approximation of human movements without taking care of the robot stability. In fact, the Robovie-X is supported by using a bracket so that all the robot limbs can move without stability limitations. The experience involves robotics topics like motion control, online data elaboration and reaction, human-robot interaction, and teleoperation.

Computer science objectives: The experience is meant to make students face high level concepts by handling a great amount of data. In fact, RGB-D sensors can provide RGB and depth images at high framerate (30 fps), and a skeleton tracking system is also available to provide additional information. Students should be able to elaborate the raw data while maintaining an elevate framerate in the robot control process. In this experience, the problem mainly concerns robot motion from a data acquisition and a procedural solution can be easily adopted. Nevertheless, students are pushed to solve it using an object oriented approach by the ROS publisher/subscriber communication protocol they learned in the previous experiences [9].

3.5 Experience 2: Robot stabilization

The goal of this experience is to make a robot picking up an object by means of human teleoperation. The robot has to automatically avoid unstable situations by balancing the input movements coming from the system developed during Experience 1. Students should apply the knowledge of robot stability learned during theoretical lessons in order to avoid situation in which the robot could fall down. The only information available about the system come from the motion performed by the human while he is observing the scene directly.

Robotics objectives: The aim of this experience is to tackle with robot stabilization problems in a humanoid robot moving like a human. Robot stabilization is the key step of the complete process used to compute suitable joint values. The algorithms developed by students have to elaborate a feedback signal to keep the robot balanced during the movement. The experience focus on a particular action the robot has to perform: grasp an object laying on the ground in front of it. Using a specific action is necessary to obtain effective results in the experience duration, since there is no sensor feedback from the robot.

Computer science objectives: This experience does not really concern a specific Computer science objective, but it allows students to apply concepts learned during previous experiences in a different environment in order to consolidate them.

4 Discussion

At the end of the course, students were asked to fill an anonymous questionnaire. The aim was to verify the correct design of the course itself. Questions of Table 1 were posed. The answer to each question is represented by a chioce among four states: *Not at all* (yellow), *A little* (red), *Enough* (blue) and *Very much* (green).

The questionnaire was meant to test key aspects of the laboratory activity:

- students' comprehension of basic concepts investigated in the previous experiences by using a mobile robot;
- effort spent in switching to a more complicated robot with a lack of sensors;
- closeness within the two activities and with possible future jobs.

Answers to the questionnaire highlight similar results for both the considered academic years. The effectiveness of the adopted method is confirmed, even by using a more articulated robot like an humanoid (Question 4). Students were able to assimilate knowledge gained by using a mobile robot and to apply it in a different manner during the following experiences being aware of the gradually increasing complexity of the proposed tasks (Question 1). The elevate number of DOFs in humanoid robots forced them to change their approach to robot control (Question 3) drawing inspiration from the similarities between humanoids and human motion, but even looking at the differences behind appearances. Students had also to balance the lack of sensors mounted on the robot by estimating the Center of Mass of the humanoids while teleoperating it through human motion. Facing this complexity make them conscious of the importance of perception in robotics (Question 2) and enable a critical analysis of possible solutions when data are missing (Question 5). Finally, the adoption of a constructivist approach in teaching robotics combined with an high level robotics framework emphasize the use of new problem solving methodologies in a new class of young, versatile engineers entering the job market in few months (Question 6).

5 Conclusion and future works

This paper presented a series of experiences based on a constructivist approach and targeted to MSc students attending "Autonomous Robotics" course. Experiences focused on controlling movements and stability of a humanoid robot.

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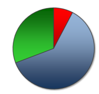
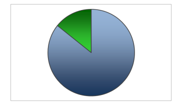
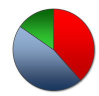
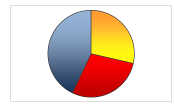
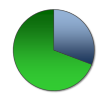
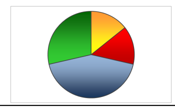
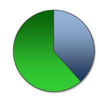
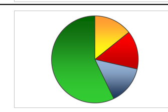
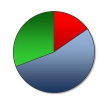
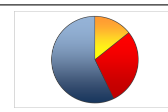
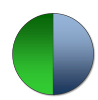
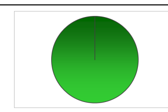
pp. 93-100

Table 1. Results of the questionnaire.

		2011/2012	2012/2013
1	The complexity of the experiences has increased with the adoption of humanoid robots in place of mobile platforms.		
2	Lack of sensors in Robovie-X platform affects robot performances		
3	The Robovie-X high number of DOFs with respect to LEGO Mindstorm NXT affected the approach adopted in controlling the robot.		
4	Using humanoid robots is the natural extension of the work started with mobile robots.		
5	Using humanoid robots gives another point of view about robotics with respect to mobile robots.		
6	In my future job I will be asked to work with modular software structures similar to ROS.		

Legend: Not at all   A little   Enough   Very much

These robot skills can be seen as a small but complete set of abilities students should gain to deal with humanoid robots. Using ROS as robotics framework pushes students to use OOP concepts thanks to the highly structured environment they have to work with and, in a broader spectrum, to deal with nowadays increasingly widespread technologies by interacting with its large user community. The analysis of a report for each laboratory experience and of the developed code made it possible to verify students' comprehension of robotics basics, their use of complex syntactic constructs and their problem-solving capabilities.

In this paper, we presented the different experiences and the way in which they were exposed to students by following an increasing complexity level. Students were asked to control robot motion and stability by means of human motion instead of analytically solving the robot inverse kinematics and dynamic in order to make them approach to the problem from a more natural point of view. The correct resolution of the assigned problems and the positive students feedback gave instructors the certainty that the proposed approach was really effective in teaching robotics.

ISBN 978-88-95872-06-3
pp. 93-100

Our goal for the future is expanding the teaching framework to include sensors and new functionalities, even offering novel robotic platforms. These kind of framework lets students deepening their knowledge in order to make them always more involved and proactive towards robotics as discipline that brings together a wide range of fields, from technology to design, from mathematics to science education.

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5th International Conference Robotics in Education
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ISBN 978-88-95872-06-3
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