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Teaching Humanoid Robotics by means of Human Teleoperation through RGB-D sensors

Stefano Michieletto, Elisa Tosello, Enrico Pagello, and Emanuele Menegatti

Intelligent Autonomous Systems Lab (IAS-Lab)
Department of Information Engineering (DEI)
University of Padova
{michieletto,toselloe,epv,emg}@dei.unipd.it
http://robotics.dei.unipd.it

Abstract. This paper presents a graduate course project on humanoid robotics offered by the University of Padova. The target is to safely lift an object by teleoperating a small humanoid. Students have to map human limbs into robot joints, guarantee the robot stability during the motion, and teleoperate the robot until performing the correct movement.

Two innovative aspects are introduced with respect to classical robotic classes: humanoid robots used as teaching tools, and the Project-Based Learning (PBL) constructivist approach adopted as teaching methodology.

Humanoid robots are not usually used as teaching material due to their high cost and their even higher complexity in motion understanding. The proposed project offers students two affordable humanoid robots (Vstone Robovie-X and Aldebaran NAO) and simplify the human-robot interaction combining teleoparation and an integrated programming framework. Teleoperation simplifies the resolution of the humanoid stability problem allowing the comparison between human and robot movements. Robot Operating System (ROS) was selected as programming framework to provide high level robotic libraries to allow students to use state-of-the-art algorithms within their own programs. The whole environment enables students to exploit movements similarities and solve complex motion problems in a natural "human" way.

Project sub-parts are composed by both practical and theoretical sections. During class lessons, the teacher exposes the needed theoretical background; while during laboratory attendances, students solve the proposed practical experiences. A PBL approach is adopted: students autonomously solve problems subdivided in groups. They are free to use their own personal ideas, the knowledge acquired in the classroom or the one inferred from the comparison with other groups. They can choose methods they think to be the best to address problems. Despite the traditional passive teaching, learning and knowledge become interactive and dynamic.

The learning objectives of both course and project are introduced and compared with the students background. For each experience we report design and constraints students have to deal with, together with the amount of time dedicated by them and their instructors. A set of evaluation results are provided in order to validate the authors' purpose, including the students' personal feedback. A discussion about possible future improvements is reported, hoping to encourage further spread of educational robotics in schools at all levels.

Keywords: Teaching Robotics, Constructivism, Project-based, Humanoid Robots, Teleoperation, ROS, Robovie-X, NAO, Kinect

1 Introduction

Humanoid robotics is an increasingly popular and challenging research field. One of the first humanoids was developed in 1973 in Waseda University (Tokyo), its name was Wabot-1 [34]. It was able to walk, to communicate with a person in Japanese and to measure distances and directions to the objects using external receptors, artificial ears and eyes, and an artificial mouth. Considerable progress has been made and several platforms have been developed and put on the market, all built to resemble the shape of the human body: from the low-cost building kits, no higher than 20 cm, to very expensive prototypes reaching almost 1.80 meters. Takes as example the humanoid robots that the DARPA Robotics Challenge [10] ranked in 2013. Existing models vary from the active ones, actuated through servomotors, to the passive structures, able to reproduce human-like motions thanks to the springs and the elastic materials with which they are built. Also perception-oriented robots exist, they are provided with a huge amount of sensors and can be considered as act-oriented machines capable of good motion.

Regardless of the application area, one of the common problems tackled in humanoid robotics is understanding the human body structure and behavior: in order to build robots, it is necessary to study the mechanisms that the human brain and the human sensory system use to acquire perceptual and motor skills. The humanoid research also helps to make prosthesis as biological realistic as possible, and humanoid robots can perform many real-world human tasks, such as nursing home assistance, construction or search and rescue in dangerous disaster areas.

The complexity of building and programming humanoid robots is deceptively great, and several knowledge is required to teach this robotics discipline. 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 project aims to overlap the obstacles arising from the use of these complex robotic platforms and aspires to maintain teaching up-to-date. The impact that humanoids have in robotics research, and the efforts that the robotics community is making to use them as service robots are known. Aldebaran is the example, with its NAO robot and the ROMEO European project [1]: a 140-cm humanoid robot intended to deepen research on assistance for the elderly and those who have lost autonomy. These efforts prompt authors to think that the new generation of engineers must have a deep awareness of the characteristics, the problems and the potential of this type of robots. E.g. Interfacing with such platforms gives students the capability to compare human movements with the humanoid motion, to fix complex issues like robot stability, multi-limb coordination, and high-DoFs inverse kinematics. Other types of robots, like the wheeled ones, do not offer these features.

Different strategies can be adopted to introduce humanoid robotics into graduate courses. Traditionally, teachers embrace the cognitive approach from Neisser [23]: students are presented with theoretical lectures and have few short practical assignments, the gained knowledge is mostly theoretical, and laboratory experiences are predetermined instructive sequences offered to solve very particular and simplified real cases. Moreover, students solve assignments individually, without cooperation and sharing. The aim of the presented project, instead, is the individual construction of students knowledge through concrete experience, collaborative discourse and reflection [6]. It is part of the "Autonomous Robotics" (AR) course of the Master of Science (MSc) in Computer Science of the University of Padova at the Intelligent Autonomous Systems Laboratory (IAS-Lab). A set of three laboratory experiences on humanoid robots is presented, with the aim of safely lifting an object using teleoperation. Students group themselves in teams and have to map human limbs into robot joints, to guarantee robot stability during the motion, and to teleoperate the robot until reaching the desired movements. The assignment subdivision, combined with a deep explanation of the underlying theory, gradually introduces students to the problem solution. This methodology, usually referred to as project-based learning (PBL) [12], is based on the Papert's perspective of Constructivism [2], and according to [26], it can be consider a constructivist teaching approach. It promotes cooperative construction of knowledge through collaboration, and encourage multiple representations of concepts and relations. Students can exchange ideas, and combine the techniques used to achieve better solutions, as the working environment requires. Asking the resolution of a problem assigning its small sub-parts in steps of increasing complexity makes students combining the concepts explained in class and their personal knowledge, improving their capability of solving problems through a scientific approach. Moreover, facing a complex real problem gives students the idea that every new algorithm implemented to extend the initial system is a way to improve their own system. This improves their interest and diligence.

The rest of the paper is organized as follows. Section 2 describes the technical details of the project (e.g. schedule, and material) detailing the three laboratory experiences and focusing on the skills that they intend to transmit to students. Section 3 summarizes the outcomes of the project during the 2011/2012, 2012/2013, and 2013/2014 academic years. In Section 4, some conclusions and future perspectives are discussed.

2 Humanoids teleoperation project

"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 Padova (Italy). It offers students methodological bases for programming autonomous robotics systems combining 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.

The task assigned aims to safely lift an object by teleoperating a small humanoid. It is worth to better explain why teleoperation is a good option for making students explore humanoid motions. There are many aspects that make the task a good teaching topic. Students are motivated by a present-day technological problem, the solution of which is part of the current robotics research. Being the problem actual, many of the techniques to be tested are not in textbooks and students have to combine their knowledge to the concepts studied in the theory lectures. Moreover, teleoperation gives them the possibility to compare human movements to robot motion, and take advantage of similarities to solve the robotic complex motion problems in a natural "human" way. As additional contribution to the student work, the sensing and acting parts in the task can be easily split to facilitate the task division. For example, the student could decide to first analyze only the human motion, than understand how to translate it to respect the robot constraints, and finally solve stability problems into the real environment.

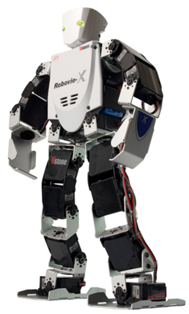
2.1 Schedule

The course lasts 12 weeks and is composed of three lessons of two hours per week. Classes are theoretical and practical: every two weeks, during the class, the teacher presents a laboratory experience that students have to solve using the theoretical foundation of previous lessons. Theory lectures and imparted laboratories are synchronized in order to offer students skills required to tackle problems.

On average, 20 students per year take the course; they are subdivided into groups of two or three people to solve the labs. It has been experimentally proved that larger groups induce confusion and unbalanced workload division within the group itself. Only one teacher attends the labs, he supervises and helps students when in doubt. No more teachers are required to successfully complete tasks. In fact, students have to solve problems alone, discussing within the group or exchanging opinions among groups. They can every day access the laboratory and use the available robots. The only constraint is presenting the solutions within three months from the end of the course. Team work and freedom to choose the approach to solve assigned problems are the basis of a problem-based learning constructivist approach [19]. This foundation makes students actively engaged in the learning process. They can actively construct individual understandings of topics using both prior and newly acquired knowledge. They develop inquiry, investigation, and collaboration skills, in turn, increasing overall comprehension of the issues [14]. This approach makes learning and knowledge interactive and dynamic. It is the opposite of traditional classrooms, in which students receive knowledge passively and work primarily alone, learning is achieve through repetition, and subjects are strictly adhered to and are guided by textbooks [13].

Most of currently robotics teachings adopt the constructivist methodology. An example is the TERECoP project [3]. The difference is that institutions joining this project base their teaching only on the LEGO Mindstorms kit [18]. Capabilities of Mindstorms robots are limited and students cannot test their programming abilities to solve more complex problems. For this reason, our labs consist of two experiences dealing with LEGO robots, followed by three experiences requiring humanoid robots interfacing. The five laboratory experiences have increasing difficulty. The first two aim to introduce students to robotics and simple, but not trivial, problems have to be solved [20]. Then, students become comfortable with the subject and humanoid robots can be introduced. Researchers report that university students in engineering courses are interested in humanoid biped robots [22] to conduce intelligent, stable, and balanced multi-Degrees Of Freedom (DOF) movements. However, the high cost of these automatons makes their usage as teaching materials a not yet widespread proposal. The University of Tokyo uses a very expensive humanoid robot, the HRP2 [24]. The Shibaura Institute of Technology proposed the E-Nuvo [35], which is less expensive than the HRP2. Nevertheless, both instruments are still expensive and can only be used by experienced users. Other experiments were conducted to lower the cost of humanoid robots and make them more accessible, so that universities could use them as teaching materials. An example is [30], which fabricated robot systems using easily available cheap key components; a servomotor of a toy and a PIC microcomputer, for example. However, these tools are still lacking. In our approach we decided to adopt two types of robots of increasing complexity: the Vstone Robovie-X [32] and the Aldebaran NAO (Figure 1). The first is a robot suitable for first time robotics builders. It has seventeen DOF and features servos. The second provides a platform for both beginners and advanced users. It has twenty-five DOF, vision, audio, and tactile sensors. Choreographe is a graphical programming environment that allows users to control the robot with little programming experiences. Additionally, Aldebaran includes a software bundle and documentation for their NaoQi middleware pre-installed on NAO. NAO may be programmed with a wide variety of languages including C++, C, Python, Java, and Urbi [11]. In our case, we use C++ and ROS (Robot Operating System) [28], a robotic framework.

The humanoids teleoperation project is composed of three experiences: 1) motion remapping: map human movements into robot ones 2) robot stabilization: use the teleoperation skills acquired on the previous step to make a robot picking up an object maintaining a stable equilibrium (no tilting is desired) 3) motion planning: plan robot motion on clutter environments. As mentioned above, tasks must be solved using ROS and tested on the real and simulated models of the



(a) Vstone Robovie-X

(b) NAO

Fig. 1. The small humanoid used in this work: Aldebaran NAO and Vstone Robovie-X

Vstone Robovie-X and the Aldebaran NAO. Gazebo [17] is adopted as simulation environment. An itemized description of the three sub-parts follows. It includes a brief description of every task, the theoretical knowledge required to face it, and the robotic and computer science objectives inferred from its successful completion and validation. More details can be found on the Lab website [16].

Experience 1: Motion remapping Students have to develop a teleoperation mapping between a human and a robot. The human motion has been acquired by a RGB-D sensor and a skeletal tracking system, namely NiTE [27]. An open-source ROS package [21] has been developed to extract skeleton information and to track them as a tree of multiple coordinate frames referred to human joints over time. Students use this standard ROS structure, called *tf* [25], in order to generate a robot motion as similar as possible to human movements.

Theoretical background: Robot Learning from Demonstration (RLfD) [4, 5] lets a system to learn a task performed by a human demonstrator and reproduce it through a robot. Various approaches exist to face the problem and several modalities exist to collect data in order to control a robot by demonstration, e.g. motion sensors or kinesthetic teaching. Motion sensors [7] must be worn by the teacher, they might be uncomfortable and prevent the human to act in a natural way. Kinesthetic demonstration [15], instead, involves robot motion guiding by a human performer. We preferred a vision system because it achieves a sufficient accuracy while maintaining the motion naturalness and the comfort of the human actor performing the task. In detail, the framework available to students [31] use an RGB-D sensor to acquire the scene (human in action). A skeleton tracking algorithm extracts the useful information from the images acquired (positions and orientations of skeleton joints); and this information is given as input to the motion re-targeting system that remaps the skeleton joints into the robot ones. After the remapping, a model for the robot motion controller is retrieved by applying first a Gaussian Mixture Model (GMM) and then a Gaussian Mixture Regression (GMR) on the collected data.

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, on line 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 frame-rate (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 frame-rate 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 [20].

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.

Theoretical background: In balancing control, the robot's Zero-Moment-Point (ZMP) [33] is the most important factor in implementing stable bipedal robot motions. If the ZMP is located in the region of supporting sole, then the robot will not fall down during motions. Moreover, to ensure a stable walk, the robot's Center of Mass (CoM) must maintain the same height during locomotion movements [8]. Assume that the motion of CoM is constrained on the surface $z = c_z$, that $c = [c_x, c_y, c_z]^T$ is the position of CoM, and the ZMP is described by the position on the ground $p = [p_x, p_y, 0]^T$. Then:

$$p_x = c_x - \frac{c_z}{g}\ddot{c}_x = c_x - \frac{z}{g}\ddot{c}_x$$

$$p_y = c_y - \frac{c_z}{g}\ddot{c}_y = c_y - \frac{z}{g}\ddot{c}_y$$

where g is the acceleration of gravity. In the case in analysis, during the execution of the teleoperated movements the ZMP must be inside the supporting sole ($p_z = 0$) and the CoM does not have to perform a movement parallel to the ground, it has to perform a trajectory perpendicular to the ground. This means $x = x_c, y = y_c$. The ZMP position follows.

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.

Experience 3: Motion Planning During this experience students have to plan the motion of the NAO robot in a 2D simulated environment populated by obstacles. The robot has to walk through a prefix path avoiding collisions with other objects around it. Students can also challenge themselves in other scenarios: 3D environments, and dynamic maps. They can also use real robots.

Theoretical background: A basic motion planning problem aims to produce a continuous sequence of collision-free robot configurations connecting a start configuration S and a goal configuration G. The robot and obstacle geometry is described in a 2D or 3D workspace, while the motion is represented as a path in the configuration space. Many algorithms have been developed with the aim of solving the problem. The Open Motion Planning Library (OMPL) [29] is the most common and powerful collection of motion planning algorithms available within the robotics community. It implements the basic primitives of sampling-based motion planning which, instead of computing the exact solution of the problem, sample the states space of the robot. Example of available OMPL planners are Probabilistic Roadmap Method (PRM) and Rapidly-exploring Random Trees (RRT) [9].

Robotics objectives: At the end of the experience the robot must (at least) walk in a simulated environment without colliding with the obstacles populating the scene. This means students have to be able to construct a 2D (or 3D) map, they must have a theoretical knowledge of the motion planning algorithms presented in class, and they must be able to apply them to find a free path from a starting to a final configuration. Moreover, the experience gained during the second project's assignment must be applied to guarantee the robot's stability during the motion.

Computer science objectives: This experience is also aimed to consolidate Computer science objectives learned during the course.

2.2 Evaluation

Students are evaluated at the three project sub-parts based on their deliverables. These consist of a report, the source code of the corresponding project part. Starting from the 2013/2014 Academic Year, a video demonstrating the proper functioning of the designed implementation is also required to be loaded in a specific YouTube channel. Students evaluation is based on two yardsticks: the complexity and originality of the approach used, and the technical writing, that means document organization, comprehensiveness, style, references, and synthesis. All skills are necessary for any engineer.

3 Discussion

This section presents the outcome of the project during several academic years. Results are discussed by looking at the students approaches to the requested tasks. Moreover, an analysis is proposed regarding the marks they received in both the specific project and the overall course. Finally, an investigation about student feedback is reported by using a questionnaire.

3.1 Exploited solutions

As highlighted in the previous sections, no specific algorithms are requested to the students in order to accomplish the tasks during the project. They had the possibility to implement a method taught them in the theoretical lessons, adopt a library already provided with useful algorithms, look for a different state of the art technique by reading scientific articles, or even develop a their own novel concept. We also take into account how students exploited ROS for fulfilling the requests given by the project. In fact, ROS is a powerful mean for speeding up the prototyping of the system and the communication between different algorithms and devices. Students used topics for spreading out information, services for acting on specific situations, and actions for tasks providing feedbacks to be monitored along time. Moreover, they could change robot model or actual sensor by simply providing a common interface for receiving data or sending commands. Several ideas have been proposed, we summarize them by analyzing the three steps composing the project.

The mapping experience has been faced mainly by using two methods. The first one consisted of matching each robot joint with a human counterpart, computing the joint angles for each of these "joint of interest". The resulting value has been used to properly move the robot. The matching phase could be very tricky depending on the selected joints, in fact the robot kinematic chain could be very different from the human one especially in some angle limits. Some students looked for the maximum and minimum of each selected human joint by testing several subjects in order to scale the computed joint values to the limitation imposed by the robotic platform. Other groups had to face a singularity problem in the selected mapping and proposed an hysteresis system to prevent rapid switching of configuration in the humanoid due to sensor noise. This method usually results very natural to users, on the other hand it is not so precise because a small error in an angle could correspond to a huge change in position. A second method has been used from some teams to avoid this behavior: inverse kinematics. They identified a sort of end effector for each limb and computed the joint angles in order to obtain similar positions between human and robot. Nevertheless, the similarity is limited to the end effector position while other joints can assume very different configurations with respect to the human body, so in some cases the robot motion seems quite unnatural to users. During the academic year 2011/2012, a team tried to overcome limitations of the already presented methods by mixing them in a hybrid solution. They fixed some joint angles by matching human and robot joints to be as natural as possible, like in the first method. While the remaining ones are computed by means of inverse kinematics in order to reach a good precision of the end effector positions. The result has proven to be quite effective and it has been widely adopted from almost all the students in the following years.

More various solutions have been proposed for the stability problem. In most cases, the final goal is to keep the Center of Mass (CoM) projection of the robot inside its ground contact area. A very simple solution considered hip (α), knee (β), and ankle (γ) joints (Figure 2) to impose a strong relation between the three joints (i.e. $\gamma = \alpha = \frac{\beta}{2}$). Some refinements have also been applied to this basic idea in order to involve all the lower body joints and at the same time adapt to the human natural behavior. More complex solutions took into account the entire structure of the robot in order to compute at each instant the ground projection of the CoM (CoM_x, CoM_y) and maintain it in a safe region. Dynamic methods involved the gyroscope to measure the robot inclination and balance it by applying an appropriate motion. In this solution, the platform has been modeled as an inverted pendulum. The stability has been guarantee by compensating forces causing the robot fall with an opposite movement of the torso. This technique is particularly suited for the picking up phase, in which the object mass has to be considered to reach the stability. A symmetric motion of the robot limbs or the definition of a safe position in case of failed tracking have been used as minor expedients to obtain a better human-robot interaction.

The part regarding the humanoid motion planning is more focused on the comprehension of a complex system, more than on finding a solution for the problem. In fact, students have to understand the connection between the virtual robot model and the algorithm performing the planning. They have been able to change several parameters and look at how the solution changed. They were

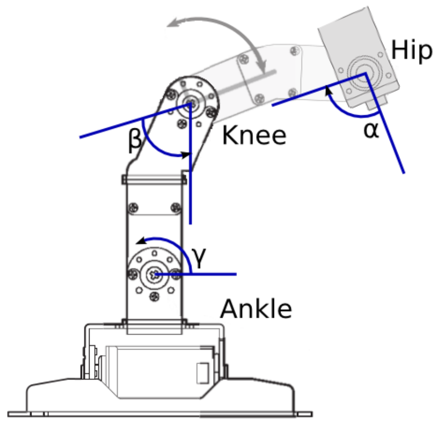


Fig. 2. Joint angles involved in a simple method to maintain the robot stability.

requested to build their own map and make the robot navigate from a point to another within it. Depending on the map, they found the proper parameters in order to reach goal even when dealing with complex paths. A number of groups have also built a map representing a real environment, while some other have tested the navigation with a real platform, namely the Aldebaran NAO.

Starting from the academic year 2013/2014, loading a video illustrating each part of the project in a dedicated YouTube channel is mandatory. Therefore, it is possible to look at the student results at `https://www.youtube.com/playlist?list=PLvyUNGk1lOSUpE1h14gFVFzX9OhPUPO08`.

3.2 Project Marks

For the project parts, the possible marks are E (not submitted), D (failed), C (mandatory), B (good), and A (very good).

Figure 3 shows the distribution of student marks for each part of the project for each year according to the requests specified in the previous sections. As can be seen, the marks are generally high: 68.6% of the students have reached the maximum mark, and only 1% have stopped their work just after the mandatory requirements. We expected such results because groups usually fulfilled the requirements by showing a good analysis of their work and often accomplishing optional tasks.

A strange trend can be noticed for the 2013/2014 Academic Year in the last part of the project. The explanation is quite simply. The laboratory schedule had to be moved forward of two weeks due to Italian holidays during the semester, anyway the exam session has started in the same period as usual. Therefore, several students decided not to perform optional tasks to better prepare other exams.

Another important aspect to notice is the lack of increasing grades during the three stages. The use of a completely different robot structure with a higher

Fig. 3. Percentage of students with respect the mark achieved in each part of the project mapping (green), stability (blue), and planning (yellow). The academic years 2011/2012 (a), 2012/2013 (b), 2013/2014 (c), and the overall students attending the course in the three years (d) have been considered.

number of Degrees of Freedom (DoFs) did not affect students capabilities to fulfill the requirements. The reasons of the achievement are manifold. The main one is the adoption of a robotics framework, namely ROS, which could be commonly used in the different experiences proposed during the course. The use of ROS as a common framework pushed students to develop algorithms in a structured environment. They are rewarded when organizing software into modules, reusing data structures and classes, exploiting class inheritance. They also experienced the power of message sharing mechanism, which is an important service offered by robotics frameworks.

These results are crucial to achieve both project and course objectives.

3.3 Course Marks

The final exam of the the Autonomous Robotics course consists of a final project in which students have to examine in depth a specific argument. The topic of the project is selected in accordance with a tutor (a professor, a post-doc, or a Ph.D. student) affiliated to the Intelligent Autonomous Systems Lab. It usually involve some topic students have learned during the theoretical lessons.

At the end of the project, student are asked to provide a small report illustrating the state of the art with respect to the selected argument and how they improve it. The expected result is very similar to a scientific paper. They also

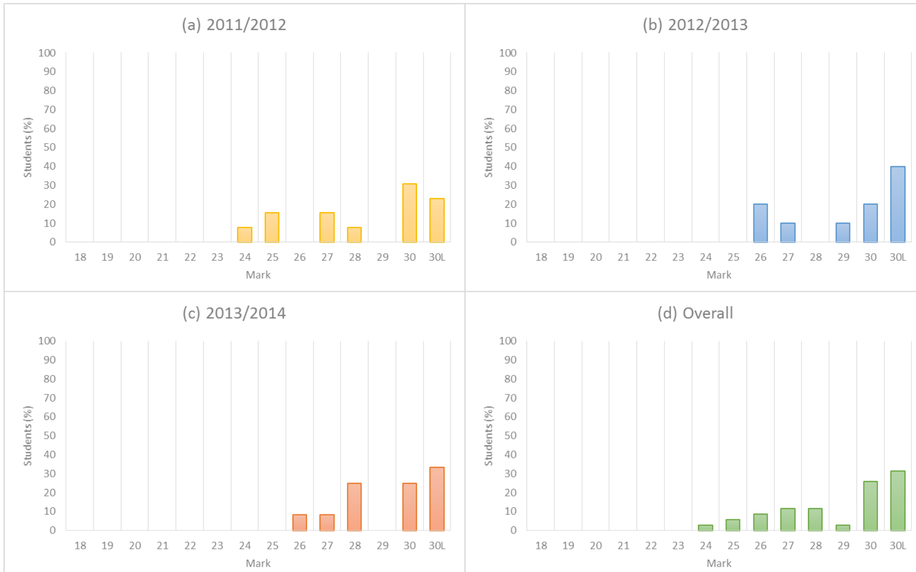


Fig. 4. Percentage of students with respect the mark achieved in the entire Autonomous Robotics course. The academic years 2011/2012 (a), 2012/2013 (b), 2013/2014 (c), and the overall students attending the course in the three years (d) have been considered.

give an oral presentation lasting 20 minutes (15 minutes for presentation and 5 minutes for questions) explaining the project. In this case, the marks go from 0 to 30 for historical reasons in the Italian University. With marks under 18, the exam is considered failed, while a "laude" can be assigned to excellent students, showing particularly brilliant results during all the course. The humanoid teleoperation project assigns a maximum of 3 point (10%) in the final grade and it is mandatory.

The graph in Figure 4 reports the percentage of students having grades from 18 to 30 cum laude during the three academic years considered in this work.

It is not very easy to compare final marks with the ones assigned to the project, but it is pretty clear that the good trend persisted. The good practices learnt from the assigned projects (the one concerning mobile robots [20] and the one presented in this paper) probably helped students. They have been able to better understand the theoretical lessons and to properly collect the knowledge necessary to build up their own robotic project. A proof of this result came from the tutors following the students during their personal project. In fact, they were able to focus their tutor work in addressing theoretical concept confirming that students are able to manage the technical part.

While this paper focuses on the humanoid teleoperation project and not on the other parts of the course, it is worth analyzing the ways in which the project improved the students experience and performance in the final exam. Clearly, the project is more engaging to students with respect to theoretical studies, anyway it is also time-consuming. Therefore, instructors have to guarantee a proper balance between theory and practice. In this work, a trade-off has been achieved by including key theoretical topics as requirements of the project steps. An example is asking for both natural robot motions and good precision in the mapping phase. No algorithm has been indicated to accomplish the task. Therefore, students have to look for possible solutions, their features and to choose the option they suppose better suit the requirements. They also have to face the consequences of their choice, and a random technique is quite rarely the best solution. Moreover, students are asked to list the motivations of their choices, the problems encountered and the possible sources of these problems in their reports. This practice helps in understanding the relevance of the selected methods with respect to the achieved results and in relating each algorithm to the theory while implementing it for the project. It could be seen as a virtuous circle in which real problems are faced by putting theoretical concepts into practice, while a solid knowledge of the theory is obtained through practical applications.

3.4 Student Questionnaire

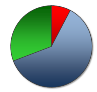
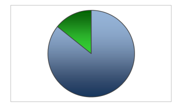
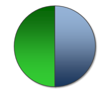
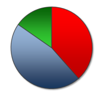
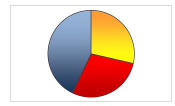
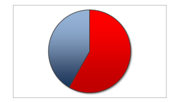
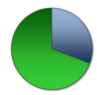
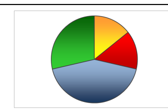
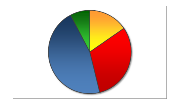
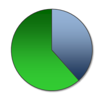
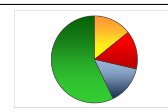
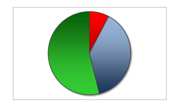
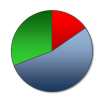
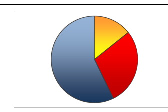
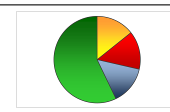
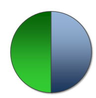
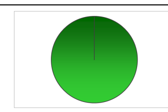
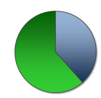
At the end of the course, students were asked to fill an anonymous questionnaire. The aim was to verify the correct design of the course itself. Questions of Table 1 were posed. The answer to each question is represented by a choice among four states: *Not at all* (yellow), *A little* (red), *Enough*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

Table 1. Results of the questionnaire.

		2011/2012	2012/2013	2013/2014
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 (yellow) A little (red) Enough (blue) Very much (green)

4 Conclusions

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. 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.

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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