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José Alexandre Gonçalves
Manuel Braz-César
João Paulo Coelho *Editors*

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Preface

Going to a conference is always an opportunity to establish contacts with other researchers and to grow culturally. Often, from informal conversations fostered by the conference's social programme, synergies are generated, leading to new ideas and partnerships. Indeed, networking is the fundamental reason for being present at any conference. Moreover, every time we visit a new country, distinct realities are observed and a kind of mild acculturation happens. Experiences gathered from travelling shape our vision of the world and promote cultural enrichment. The CONTROLO 2020 Conference was intended not only to be a scientific event, but also to give the opportunity for the control community to know Bragança, the Polytechnic Institute of Bragança, and to network face-to-face in friendly, safe, stimulating and international environment. The city was prepared to receive this scientific community, with a welcome reception at the Castle of Bragança and a gala dinner at the gardens of the Abade de Baçal Museum, providing all the participants to get in touch with some of the most important landmarks of the Bragança cultural heritage. The ideal situation would be to communicate in person but, due to the current pandemic situation, the CONTROLO 2020 Conference was forced to change to an online event. In spite of all these difficulties, the decision to maintain the date of this event has demonstrated the resilience of APCA in adapting to extreme conditions. In addition, it was also important in this decision-making, to ensure that the dissemination of the research and development works, submitted and accepted for publication, would be made public in due time.

A total of 93 papers, originating from 39 different countries, were submitted for publication, from which 76 were accepted, after an evaluation process that totalled more than 300 reviews. Besides its six special sessions and a MATLAB course, the CONTROLO 2020 Conference had the honour of having five of the most relevant personalities in automatic control community in its five plenary sessions, namely professors André Preumont, Eduardo Camacho, Karl Johansson, Kevin Passino and Sebástian Dormido. We hope that all interested readers can benefit scientifically from this conference proceedings.

Best Regards,
CONTROLO 2020 Local Organizing Committee

A DOBOT Manipulator Simulation Environment for Teaching Aim with Forward and Inverse Kinematics

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Abstract. Industrial Manipulators were becoming used more and more at industries since the third industrial revolution. Actually, with the fourth one, the paradigm is changing and the collaborative robots are being accepted for the community. It means that smaller manipulators with more functionalities have been used and installed. New approaches have appeared to teach students according to the new robot's capabilities. The DOBOT robot is an example of that since it captivates the student's attention with an uncomplicated programming front-end, tools, grippers and extremely useful for teaching STEM. This paper proposes a simulation environment that can be used to teach, test and validate solutions to the DOBOT robot. By this way, the student can try and validate, at their homework without the real robot, the developed solutions and further test them at the laboratory with the real robot. Currently, remote testing and validation without the use of a real robot is an advantage. The comparison of the provided simulation environment and the real robot is presented in the approach.

Keywords: Simulation, Teaching, Problem Based learning, Project Based Learning, Manipulator robots

1 Introduction

Robotics is an interdisciplinary science that great potential for education. It requires several areas of knowledge to understand its concept fully. In the last few years, according to [1], robots' presence increased in the education market, both as tools to motivate students to explore STEM (Science, Technology, Engineering and Mathematics) disciplines and as curriculum materials for teaching content. In fact, several attempts have been made worldwide to introduce robotics in science and technology subjects in schools, from kindergarten to high school [2].

It can be taught in class, as projects or even by competition as it encourages the students to develop solutions to tasks [3].

To motivate robotics in education, it is necessary to make this technology accessible to students. In this way, there are some approaches to do this - for instance, educational programs from governments, organizations, and enterprises to bring robotics to schools. Alternatively, reduced costs of robotics components and the development of low-cost educational kits helps to spread the technology to students. Finally, there are simulations. Although they don't offer the opportunity to experience the robotics' components at hand, it provides a realistic experience to a real scenario without costs. Moreover, simulations software are nowadays capable of simulating non-idealities and dynamic constraints of the real scenario such as friction, uncertainty, measurement noise, among others. It is a tool that allows students, at their homework, to develop a solution and validate it on the real scenario at the classroom later. Besides, they offer a peaceful transition from the simulation environment to the real world, minimizing development costs. Hence, they became a mandatory step in research and development projects.

This robotic arm was designed for practical education. For this reason, it has several advantages such as being small, low-cost and easy to learn (it can be coded with visual programming language). Moreover, it is easy to change the tools that can be attached to the arm. However, one considerate disadvantage is that this robot does not have a simulation platform. For this reason, students are obliged to purchase the robot or, if their education institution has one, they need to remain inside the institution's laboratory to study. Consequently, simulations must be the most realistic possible to permit that the simulation's code works in the real world, allowing students to study robotics. Thus, this work presents a simulation tool, based on SimTwo, that helps to develop, test, and validate programs that after will be run in the DOBOT Magician manipulator.

This work is structured as follows: after the introduction, a brief state of the art is presented in Section 2. After, in Section 3, the DOBOT manipulator is explained. The results are shown in Section 4. The conclusion and future work are discussed in Section 5.

2 State of Art

According to [2], research in robotics in education focused on the interaction between the invention of new technologies and the development of new ways of learning. Furthermore, with the purpose to make children active participants in education, research since the '60s has been made to develop robotic construction kits [2]. This concept is emphasised by Jeffrey Johnson [4], claiming that robotics provides an effective way for children to learn many of the things on the national curriculum for science, technology, and mathematics. He also states that robotics is arguably the most effective way of motivating and supporting the study of the many areas of the curriculum. As stated by [5], an underwater robotics program for middle and high schools and was developed by the Stevens Center for Innovation in Engineering & Science Education at The Stevens Institute of Technology. She states that its purpose is to teach students engineering design and STEM concepts and at the same time increasing awareness in engineering, and IT careers. Besides, organisations such as AAAI (Association for the Advancement of Artificial Intelligence) and IEEE (Institute for Electrical and Electronics Engineers) and others hold tournaments for their students members at their significant conferences [1]. He states that it motivates them to pursue relevant degrees by sharpening the students' skills by the robot's construction-related activities, getting them excited about technologies and businesses linked to that organisation. Regarding education robot platforms, many research institutions and universities continue to develop custom platforms such as Honda's Asimo or even research platforms such as iCub and Willow Garage's PR2. Moreover, he states that low-cost kits and platforms are becoming widely used in primary, secondary and higher-level education throughout the world. In [6], is presented a low-cost printable bots that could be incorporated in university engineering disciplines as educational mechanisms. Therefore, it is possible to explain the hardware and programming tools of an educative robotic platform based on low-cost open source technologies.

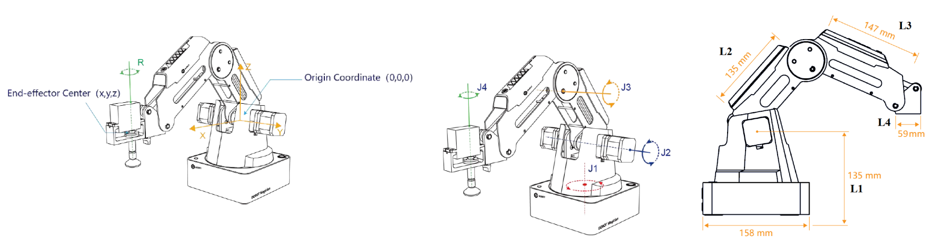
3 DOBOT manipulator

After significant advances in robotics over the years, there has been an explosive growth in the range of robotic applications in the industrial sector, in particular the use of the palletizing structure. This type of robotic manipulators is commonly used in manufacturing, handling, process operation, assembly, inspection and other processes [7]. Due to this vast increase in industrial applications, implementing an educational robot model that resembles that used in industry is extremely important for students' learning in schools, institutes and universities.

Fig. 1: DOBOT Magician working in education method [8].

According to [8], DOBOT Magician is a multifunctional desktop robotic arm for practical education, as can be seen in Figure 1. It can perform 3D printing, laser engraving, writing, and drawing depending on the tool attached to the end-effector. This robot supports 13 extensible interfaces and over 20 programming languages for secondary development. Being low-cost, small in size, and with easy operation, every student can practice on their own. Moreover, it can be controlled by APP, Bluetooth, Wi-Fi, mouse, among others. By supporting multi-robot collaboration, it is possible to control several DOBOT Magician using the same device. It was successfully applied by many institutions and enterprises such as Tsinghua University and Volkswagen.

Figure 2 shows illustrations of the DOBOT Magician scheme, where it is possible to view the point of origin of the robot (Figure 2a), with the orientations of each joint represented by $J_1 \dots J_4$ in the Figure 2b, and in the Figure 2c, it shows each of the necessary distances for performing forward and inverse kinematics.



(a) Point of origin in the Cartesian plane.

(b) Connections between the joints and their orientations.

(c) Distances between each joint and the height from the point of origin.

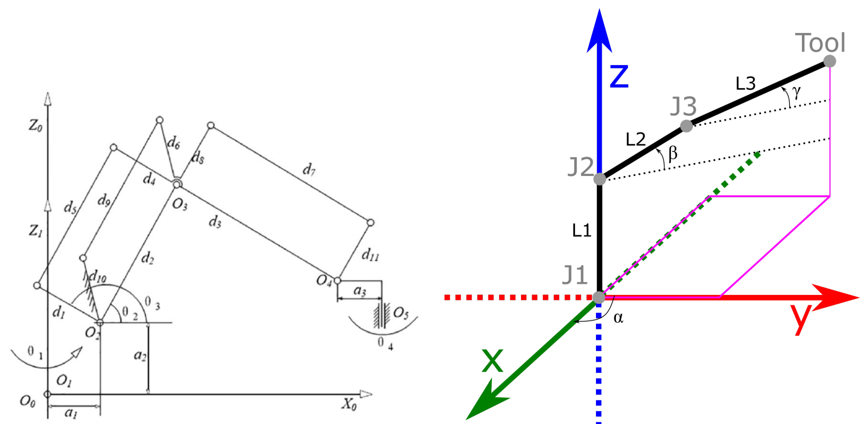
Fig. 2: DOBOT Magician scheme. Adapted from [8].

Compared to industrial manipulators, this model is relatively inexpensive. However, equipping a classroom with a model for each student would become an additional investment. On the other hand, keeping only a few copies at the disposal of students can cause long queues between them. Therefore, a possible solution to this problem is to create a simulated environment that approximates the real characteristics of DOBOT Magician. In this way, students can test their scripts with the simulation tool before putting them into practice in real situations, and consequently, avoiding numerous inconveniences.

3.1 Forward and inverse kinematics of DOBOT

Some techniques must be developed to identify the positions of specific points on the robotic arm, as well as to determine the Cartesian Coordinates from which the tool (end-effector) is acting. This identification depends on the structure of the joints and links (parts connected through the joints) in reference to some point, which is usually the basis of the manipulator itself. Determining where is the end-effector is of great importance for industrial processes, therefore demonstrating this study to students through DOBOT Magician can become a promising and engaging approach.

In this way, the kinematics for manipulators is responsible for studying movements without considering the causes that originate them [9]; therefore, the kinematics will deal with distances, angles, accelerations and translation and angular speed [10]. To determine kinematics in manipulators is necessary a careful study, even for robotic arms with few Degrees of Freedom (DoF) such as the DOBOT Magician (assuming the configuration with 3 DoF, because this work approach does not need the J_4). Figure 3a shows the number of variables and the complexity of kinematics.



(a) Example of palletizer robot connecting-bar [7].

(b) Representation of DOBOT Magician in 3D vectors.

Fig. 3: Demonstration of DOBOT Magician geometry.

To simplify the geometric analysis, it is possible to transform each robot link into a three-dimensional vector and then carry out the projections of these vectors through trigonometric functions. Figure 3b shows the DOBOT Magician vector analysis. Where each dimensional variable has the same configurations that the manufacturer provides (Figure 2), that is, the same number of joints (J_n) and lengths (L_n). The base angle is called "alpha (α)" (generated by the movement of J_1), whereas the angle formed by the joint J_2 is declared as "beta (β)", and consequently, the angle formed by the last joint J_3 is defined by "gamma (γ)". Therefore, it is possible to obtain the coordinates of the end-effector in XYZ through the angles of each joint, that is, the forward kinematics is defined by the following expressions:

$$X = radius.\cos(\alpha) \tag{1}$$

$$Y = radius.\sin(\alpha) \tag{2}$$

$$Z = L_1 - L_2.\sin(\beta) + L_3.\sin(-\gamma) \tag{3}$$

where

$$radius = (L_4 + L_2.\cos(\beta) + L_3.\cos(\gamma)) \tag{4}$$

This means that with the use of Equations 1-4, it is feasible to determine where the end-effector will be when the angles are known. Hence, it can be used to configure the simulated environment to synchronize the motion with the real robot.

Similar to that performed for forward kinematics, that is, by making the projections of the vectors indicated in the Figure 3b, it is possible to identify the angles that each joint forms (α, β and γ) to reach with the end-effector a certain known XYZ point. In other words, it is possible to determine the inverse kinematics. To do this, simply apply the following expressions:

$$\alpha = \arctan\left(\frac{Y}{X}\right) \tag{5}$$

$$\beta = \left(\frac{\pi}{2}\right) - (Q_1 + Q_2) \tag{6}$$

$$\gamma = \left(\frac{\pi}{2}\right) - \arccos\left(\frac{L2^2 + L3^2 - hypotenuse^2}{2.L_2.L_3}\right) \tag{7}$$

where

$$Q_1 = \arctan\left(\frac{Z}{radius}\right) \tag{8}$$

and

$$Q_2 = \arccos\left(\frac{L_2^2 - L_3^3 + hypotenuse^2}{2.L_2.hypotenuse}\right) \tag{9}$$

In this approach, the *radius* needs to be written according to the known XY coordinates:

$$radius = (X^2 + Y^2) - L_4 \tag{10}$$

And the *hypotenuse* variable is defined by:

$$hypotenuse = \sqrt{Z^2 + radius^2} \tag{11}$$

It is commonly seen that inverse kinematics can generate infinite values for some angles when knowing the XYZ point of the end-effector, as seen in [11]. However, the DOBOT Magician manufacturer specifies in the manual that some joints are limited, and this problem does not happen [8]. For this reason, this work does not address the treatment of infinite values at angles. Therefore, Equations 1-11 can be inserted in the simulator settings, so that the simulated robotic arm can be moved equally with the arm used in the real situation.

4 Results

Simulation environment was based on SimTwo [12]. The environment model will be available to help students for the off-line development and training. The STL files (provided by the manufacturer) were converted into 3DS format and the entire assembly of DOBOT Magician in SimTwo is shown in the Figure 4, with the suction tool fixed at the end-effector.

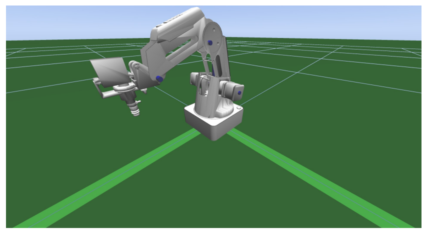
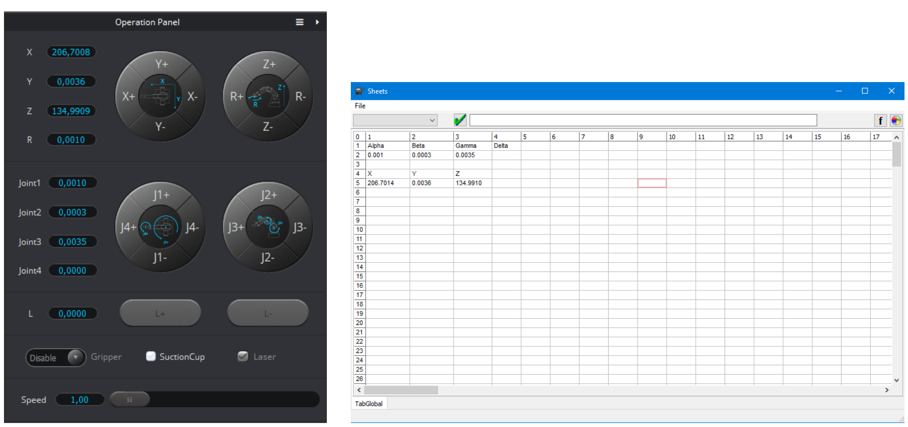


Fig. 4: SimTwo scenario with a 3D model of the DOBOT Magician manipulator.

The tests have the as main objective to compare the performance of the simulated robot in SimTwo with the real robot. For this, the first step is to determine the reading of each value. In Figure 5, it is possible to see the options panel of both, that is, in Figure 5a, the panel showing the official DOBOT Magician software informs the tool's coordinate and the angle values of each joint also. Therefore, in Figure 5b, it is shown how the values are displayed during the simulation, resembling as close as possible to the official version.

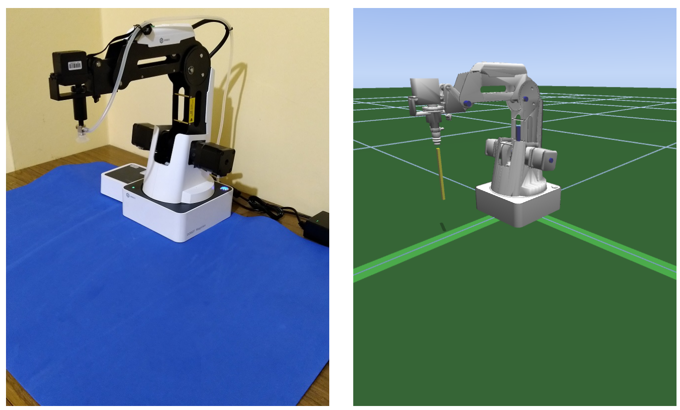


(a) The official Option Panel. (b) The SimTwo panel.

Fig. 5: Comparison between the official option panel and the simulated panel.

Based on information from the official options panel, nine points are chosen within the real robot's workspace. As mentioned earlier, this work does not consider DOBOT Magician's last DoF due to the application of the suction tool does not need to use this degree to perform actions. Therefore, the informed values R and J_4 will not be necessary for the tests of this work.

One by one of the nine points are inserted in SimTwo to perform the movement analysis between the real and simulated scenario, as shown in Figure 6. Therefore, the first point is inserted in the software of the real robot (Figure 6a), and then the same point is inserted in the simulation, shown by Figure 6b. To avoid doubts about the tool's positioning in the simulated environment, a yellow cube is placed in the same coordinates. In this way, it is possible to check if the point of the simulated suction tool is positioned in the expected coordinate.



(a) Real DOBOT Magician. (b) Simulated DOBOT Magician.

Fig. 6: The first point that compares the pose between real and virtual robot.

Since the values obtained with the software of the real robot can serve as parameters, the inverse and forward kinematics can be tested. During the tests of forward kinematics, it is established that SimTwo must generate the XYZ coordinates as close as possible to those of DOBOT Studio through the inserted angles. In this way, Table 1 describes the nine values of J_1, J_2 and J_3 (from DOBOT Studio), and the values that SimTwo generated from the tool coordinates (defined as X', Y' and Z'). Therefore, the error values are made according to the difference between the coordinates generated by SimTwo with the coordinates of DOBOT Studio. For example, the error of the X coordinate (E_X) is produced by $E_X = X' - X$, and consequently, the same for the other coordinates.

Similarly, tests with the inverse kinematics configured in SimTwo are based on the values provided by DOBOT Studio. However, during the tests, the comparison of the simulation with the real environment is made with the generated

Table 1: Results of forward kinematics applied in SimTwo.

X'[mm]	Y'[mm]	Z'[mm]	J_1[°]	J_2[°]	J_3[°]	E_X[mm]	E_Y[mm]	E_Z[mm]
From SimTwo			From DOBOT Studio			$X' - X$	$Y' - Y$	$Z' - Z$
206.7014	0.0036	134.991	0.0010	0.0003	0.0035	0.0006	0.0000	0.0001
206.7006	0.0036	0.0041	0.0010	27.3328	54.6673	0.0007	0.0000	-0.0001
140.2823	0.0024	0.0048	0.0015	8.2131	65.3559	0.0007	-0.0012	0.0000
325.3315	0.0057	0.0058	0.0006	69.4926	18.7652	0.0007	0.0021	0.0002
220.2139	151.8048	0.0056	34.5805	45.1669	40.3497	0.0006	0.0004	-0.0002
150.5779	-162.442	-65.1879	-47.1706	56.9885	70.6978	0.0006	-0.0006	0.0000
245.597	-48.3805	-64.5283	-11.1441	61.7856	60.8264	0.0007	0.0000	-0.0001
121.0937	152.734	-68.2998	51.5912	55.3750	80.5549	0.0004	0.0005	0.0001
246.4169	154.7887	-65.9097	32.1353	72.9032	45.9187	0.0006	0.0004	-0.0001

joints. In other words, in these tests, the objective is to insert the XYZ coordinates (from DOBOT Studio) in the SimTwo panel and analyze which angles are generated, namely J_1', J_2' and J_3'. Table 2 has each of the nine probe points, as well as the values of the errors found. These are defined by the difference between the angles generated by SimTwo and those provided by DOBOT Studio. For example, the Joint 1 error (E_{J_1}) is characterised by $E_{J_1} = J' - J$, so the same method is used in the other joints.

Table 2: Results of inverse kinematics applied in SimTwo.

X[mm]	Y[mm]	Z[mm]	J_1'[°]	J_2'[°]	J_3'[°]	E_{J_1}[°]	E_{J_2}[°]	E_{J_3}[°]
From DOBOT Studio			From SimTwo			$J_1' - J_1$	$J_2' - J_2$	$J_3' - J_3$
206.7008	0.0036	134.9909	0.0010	0.0000	0.0035	0.0000	-0.0003	0.0000
206.6999	0.0036	0.0042	0.0010	27.3326	54.6674	0.0000	-0.0002	0.0001
140.2816	0.0036	0.0048	0.0015	8.2129	65.356	0.0000	-0.0002	0.0001
325.3308	0.0036	0.0056	0.0006	69.4922	18.7657	0.0000	-0.0004	0.0005
220.2133	151.8044	0.0058	34.5805	45.1666	40.3499	0.0000	-0.0003	0.0002
150.5773	-162.4414	-65.1879	-47.1706	56.9884	70.6981	0.0000	-0.0001	0.0003
245.5963	-48.3805	-64.5282	-11.1441	61.7854	60.8266	0.0000	-0.0002	0.0002
121.0933	152.7335	-68.2999	51.5912	55.375	80.5552	0.0000	0.0000	0.0003
246.4163	154.7883	-65.9096	32.1353	72.9029	45.919	0.0000	-0.0003	0.0003

To validate the proposed approach, it is expected that the SimTwo simulator would have the same performance as performing the applications through DOBOT Studio. During the analysis, it is noted that the developed forward kinematics obtained error averages of 0.0006, 0.0002 and 0 for XYZ, respectively. With these average error values, it is possible to make the error in terms of the Euclidean distance, that is, $E_{Euclidean} = \sqrt{0.0006^2 + 0.0002^2} = 0.000\,632\,4\,\text{mm}$. For the inverse kinematics, the average error obtained for J_1 was 0, and in J_2 and J_3 had 0.0002.

5 Conclusion

In this paper, a simulation environment for the DOBOT commercial platform was presented. The forward and inverse kinematics of such robot are addressed and implemented on the simulator. The developed tool will allow students to do the work as if they had a real robot. Results demonstrated that the simulator is capable to execute the trajectories in a similar way as the real one and with an error of positioning of 0.0006 mm (Euclidean distance) compared with the real platform IDE for the forward kinematics and almost zero degrees for all joints on the inverse kinematics. As future work, it is planned to develop an interpreter for the DOBOT files in order to increase the compatibility between real and simulation, that means, students can use the same files at both robots.

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