Open-source Robot Arms in Research and Education

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***Abstract*— There is a growing industrial demand on engineers with up-to-date robotics knowledge which requires the improvement of the theoretical and practical education of robotics on university level. This paper proposes an environment for teaching the planning, assembly and programming of robotic arms. Two open source platforms, Nyrio One and BCN3D Moveo, are reviewed from research and educational point of view.**

Keywords—robotic arm, Arduino, Raspberry, educational robots, industry 4.0, digital education

I. Introduction

As digital education is increasingly gaining ground [1]–[3], state-of-the-art topics like robust engineering solutions [4]–[6], predictive maintenance [7]–[10], industry 4.0 [11], [12] , robotics [13], [14], control theory [15]–[18] or sensor technology [19]–[21] need new concepts for the structure of the university curriculum. Thus, a further challenge of this aspect is the modification of the laboratories to meet these new requirements.

In today's world, robots play an extremely important role, without which it would be almost impossible to meet the needs of the world. For instance, the production of cars alone, or the mass production of any product where 6-axis industrial robots help, or may completely replace, human labor. This is not surprising, as they are able to move loads of up to hundreds of kilograms, and they can also operate around the clock. Thus, it is worth automating most of the manufacturing processes, which can be solved in accordance with the economical requirements. With the application of automation, almost any process can be performed quickly, precisely, efficiently, from welding, painting and packaging, to servicing CNC machining centers.

II. Problem Description

The implementation is based in the Robotic Center of the Alba Regia Technical Faculty of Obuda University. The main purpose of this paper is the introduction of a 6-axis desktop robot arm, on which students can get acquainted with the basics of robotics. One of these would be available to each student, or one per group of two people. Thus, one of the primary considerations would be to minimize the cost of making such a robotic arm. Using 3D printing technology, the production of more complex elements can be done extremely cheap. For the introduced prototype a Wanhao Duplicator i3 printer were used. The axes of the robot arm are NEMA 17 stepper motors and MG995 servomotors. As control unit Raspberry, Arduino Mega 2560 microcontroller and Ramps 1.4 control panels are used.

III. BCN3D Moveo

The first investigated open source robot arm is called BCN3D Moveo [22] (see Fig. 1). The aim is to assemble the complete unit from the lowest possible budget using commercially available elements. This requirement made a few modifications necessary on the original open source model. The last shaft of the original model is driven by a NEMA14 standard size stepper motor. As it was not commercially available in Hungary, it had to be redesigned to accommodate a NEMA17 motor. As the motor is larger than the original, the model had to be strengthened at the relevant geometries.

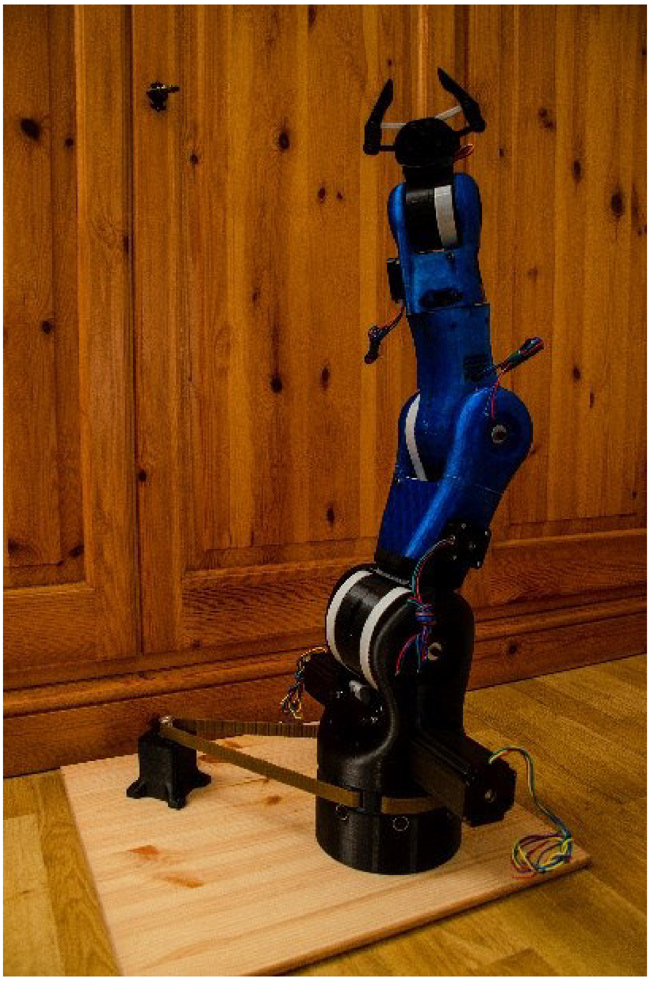

Fig. 1: BCN3D Moveo

PETG was chosen as the raw material for 3D printing. The finished workpieces are a bit brittle, but this durable material with a higher fill value is extremely solid. It can withstand multiple crashes and still perform its tasks. Furthermore, since all its elements are made in 3D printing, they can be replaced with a commercial printer in case of more serious damage. As several mistakes occurred during the assembly, elements had to be replaced. Once the right printing technology was found, replacing them was easy and fast. Some of the commercial material required a little finishing, e.g. the toothed pulley was delivered raw. Thus, the center holes and fixing threads on them had to be made. Also, 3D printing technology includes a bit of finishing work in all cases, because the “supports” must be removed and the contours have to be deburred. A university workshop, fablab provides all the tools to perform these basic tasks. In case all the mechanical elements arrived, and everything is at our disposal, assembling is not a difficult task, which can be done in 3-4 days even by an inexperienced university student (see Fig. 2).

Fig. 2: Assembly of BCN3D Moveo

The setup offers a wide range of possibilities for the education of engineers from different fields (see Fig. 3). As control unit amongst others Arduino or Raspberry might be used. As software Node-RED, ROS or MATLAB might be applied. Since it contains only simple stepper motors, the robot can even be operated with a PLC. Talented students can even add modifications with their own improvements to improve the mechanical printed element of the robotic arm, like reducing the weight of the arm, developing a more appropriate gripper or mapping current weak points with a load test.

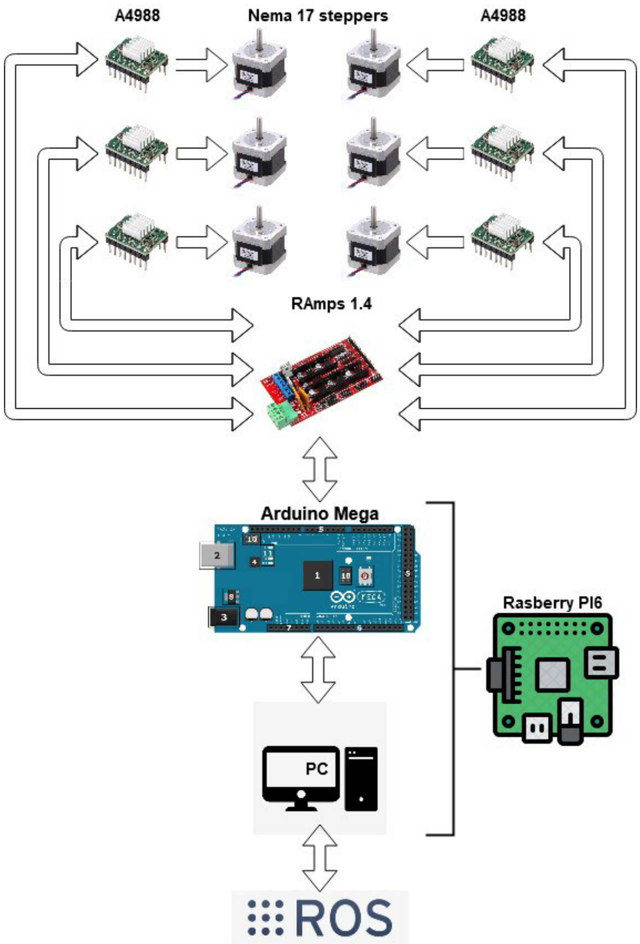

Fig. 3: Control architecture of BCN3D Moveo

Purchasing all mechanical parts, the price of the robotic arm can be kept below 350 EUR facilitating that each workstation in the training room can have its own robotic arm. Students can create their own robot arm for the educational material, gain experience, how to make an automated machine. They have insight into the whole process. Considering the safety aspects, industrial robots are dangerous and require a lot of care. This way, students can acquire the necessary programming basics in a safe environment. With the knowledge they have already acquired, they will be ready to start with the industrial robots of the university like the Fanuc, Universal Robots, KUKA and ABB education cells with more confidence and humility.

IV. Nyrio One

The second investigated open source robot arm is called Nyrio One [23] (see Fig. 4). The axes of the Nyrio One consist of 4 NEMA 17 stepper motors and 2 MG995 servomotors, and the gripper is also operated by such a servo. For programming an Arduino Mega 2560 microcontroller and a Ramps 1.4 control panel were applied, which is primarily designed to control the axes of 3D printers but is also perfect for this purpose. Several A4988 motor control circuits are also required to move the stepper motors.

Fig. 4: Nyrio One

The robot can be purchased from Nyrio's official website for a few thousand dollars, which is relatively expensive, but everyone has access to the models, source codes, and lists of mechanical and electronic parts needed to purchase. In view of the relatively inexpensive implementation, the robot has been modified in several respects.

Considering the easy printability, both the PLA and PETG correspond to the raw material of the robotic arm. The smaller elements were printed from PLA, while the larger ones were printed from PETG. The parts printed from PLA were made using a proprietary Wanhao Duplicator i3 Mini printer, the slicing software used is Wanhao Cura, Settings for 3D printing:

• Heating block temperature: 210 ° C

• Print speed: 60-70 mm / s

• Nozzle diameter: 0.4 mm

• Wall thickness: 0.8 mm

• Layer height: 0.2 mm

• Fill factor: 20%

• The use of a support is necessary in most cases

Most of the parts were printed based on the original STL files without modification, but the elements related to the last 2 axes needed redesign due to the MG995 servomotors. In addition, I wanted to mount the gripper of of the BCN3D MOVEO, on the Nyrio, thus the design of an adapter was necessary. The robot would include two more 100 mm long aluminum tubes, which were also made of PLA material, which made the robot a bit lighter. With this element, however, the correct orientation of the form must be taken into account during printing, since the torques acting on the finished workpiece allow the layers to separate from each other, so it is worth printing this tubular piece horizontally, so this phenomenon can be eliminated.

The assembly videos on Nyrio's official website are useful, but there are some issues and problems that arise during construction. It is advisable to prepare the already printed elements before assembling, first remove all the supporting materials from the pieces. After that, any surface defects in the printed elements should also be removed by sandpaper and a hand-held mini sander.

The first 4 shafts are driven by a NEMA17 stepper motor, the first 3 motor shafts have a GT2 type ribbed wheel, the torque of the robot's shafts is driven by a GT2 ribbed belt, the belt tension can be adjusted with M3 bolts and self-locking nuts. An endless strap was placed on the first axis of the robot, I solved the endlessness of the strap with gluing and a thread with a thin line. The stepper motor responsible for driving the fourth shaft is equipped with a planetary gear with a ratio of approximately 1: 5, the torque of which is transmitted by a small clutch, which allows a slight distortion in both the axial and radial directions due to possible angular errors. On the 5th and 6th axes, MG995 servomotors provide rotational movement, which can be easily installed with a few screws. Due to the low load, it is not necessary to use a gear unit on these shafts.

With the exception of the last, 6th axis, all axes are equipped with bearings, and due to their construction, the first and fourth axes, in addition to the radial deep groove ball bearings, also have axial ball bearings to ensure the smooth movement of the robot. It is also worth mentioning the torsion steel spring located in the second shaft (see Fig. 5), which takes over part of the torque from the loads from the stepping motor responsible for driving the shaft, thus providing the motor with the correct value of the holding torque so that it will not lose step.

Fig. 5: Assembly of Nyrio One

The created robot can be moved in a simulation environment using a robot operating system (ROS) running on Ubuntu installed on a virtual machine, followed by the movement of the real, physical environment (see Fig. 6).

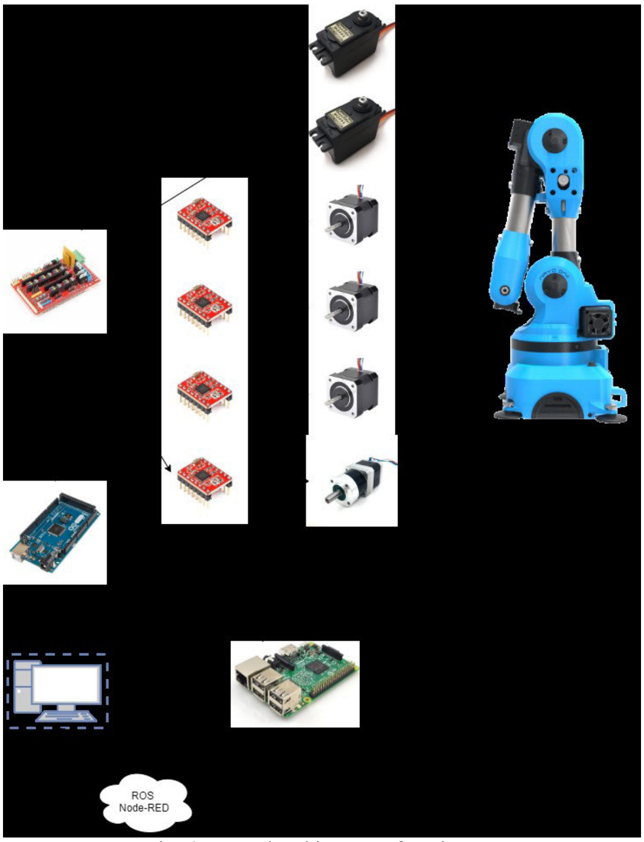

Fig. 6: Control architecture of Nyrio One

V. Further Possibilities

There is a lot in common between a robot arm and a 3D printer: stepper motors, motor controllers, etc. This facilitates the design of various devices applying the same elements. Students first create a custom 3D printer as a low-budget project. Its size is such that it can easily make the largest element of the robotic arm outlined above. Students learn about the technology with all its pros and cons. They acquire the necessary knowledge to control the motors with the help of ARDUINO. They can develop their programming or mechanical assembly knowledge. Later, they can print the above-mentioned robot arm on this printer. As a next step, by disassembling the 3D printer, the purchased and printed elements can be transformed into a robotic arm using almost all the components of the printer, such as bearings, stepper motors and the associated motor controls, belts etc. Only a few new parts are necessary. With this transformation option, university education can be taken to a new, higher and more practical level.

VI. Conclusion

The paper introduced the application of two different open source robotic arm models for the use of university studies and research purposes. The purpose of the experimental setups is to introduce the mechanical, electrical and software structure of a robotic arm on university level. The proposed environment facilitates the education of several engineering fields with relatively low costs.

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