Integrating Cobots in Engineering Technology Education

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Abstract

Collaborative robots or CoBots, unlike traditional robots, are safe and flexible enough to work harmoniously with humans. Exploiting the efficiency of automated operations and the flexibility of manual operations in one process can improve productivity and worker job satisfaction. CoBots technology has been experiencing strong growth in different areas such as ground transportation, food-processing industry, car manufacturing, and naval or aeronautical engineering. Current CoBots education and training opportunities are rare or non-existent in university environments. In response to this need, we developed several CoBots modules which will be integrated in the current robotics and mechatronics courses. In this paper we are presenting one common module which will be integrated in both, robotics and mechatronic courses. This module is about modeling and validation of Baxter Collaborative robot kinematics using Matlab tools. Through the validation and visualization of the kinematic equations, students will be able to connect the robotic and mechatronic theory with different applications using the latest technology.

Introduction

A ‘CoBot’ (from collaborative and robot) is a robot planned to physically interact with humans in a shared workspace [1]. Initially invented in 1999 by Professors Edward Colgate and Michael Peshkin at Northwestern University in Evanston, Illinois [1]. CoBots technology has been experiencing strong growth in different areas such as ground transportation, food-processing industry, car manufacturing, and naval or aeronautical engineering, CoBots are are capable of working with human workers instead of replacing them.
Because collaborative robots (cobots) work by human side, a new technology that has the goal of increasing safety has been developed. In addition, they have rounded surfaces, power

limit and speed limit, and collision detection [2]. Today most companies are looking forward to this technology as it saves a lot of money that is spent on building separate cages and isolated workspaces for classic robots [3]. Also the portability and capacity to work in a reconfigurable set-up makes collaborative robots the best choice for dynamic companies who need to change their assembly lines with ever growing customer expectations. The focus of the paper [4] provide a foundation and four tier framework to facilitate the design, development and integration of CoBots. The framework consists of the system level, work-cell level, machine level, and worker level. A thorough review of the literature, safety and layout challenges, and contemporary factory automation configurations using solutions that have been introduced to the market will be presented, as well as a roadmap for education and research challenges, [4]. The kinematic equations for the 7 Degrees Of Freedom collaborative robot Baxter has been presented in [5]. This model is validated using experimental procedure.

With a predicted 150,000 cobots to be installed worldwide in the next three years and cobot's expected impact on productivity and workers safety, there is an urgent need for higher education institutions to incorporate this technology in advanced training programs in order to develop a career-ready workforce that will support U.S. global manufacturing competitiveness. Current CoBots education and training opportunities are rare or non-existent in university environments. In response to this need, we developed several CoBots modules which will be integrated in the current robotics and mechatronics courses. In this paper we are presenting one common module which will be integrated in both, robotics and mechatronic courses. This module is about modeling and validation of Baxter Collaborative robot kinematics using Matlab tools. Through the validation and visualization of the kinematic equations, students will be able to connect the robotic and mechatronic theory with different applications using the latest technology.

Baxter Kinematic Model

Baxter® is the collaborative robot made by Rethink company. The Baxter® robot arms have seven rotational joints in each arm and these are named s0, s1, e0, e1, w0, w1, w2 starting from the shoulder respectively and are shown in Figure 1, [6].

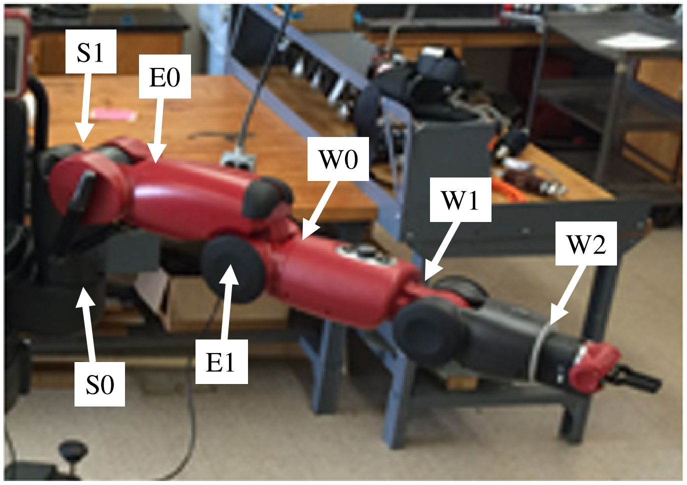


Figure 1: The arms of Baxter® robot with 7 Joints in each arm [5, 6]

Using the robot kinematic theory the Baxter mathematical model has been developed and validated, [5]. This model is used in the CoBot common module which will be integrated in both, robotics and mechatronic courses. The model has been developed using five steps:
Step (a) development of the Baxter kinematic diagram, [5]. See Figure 2.

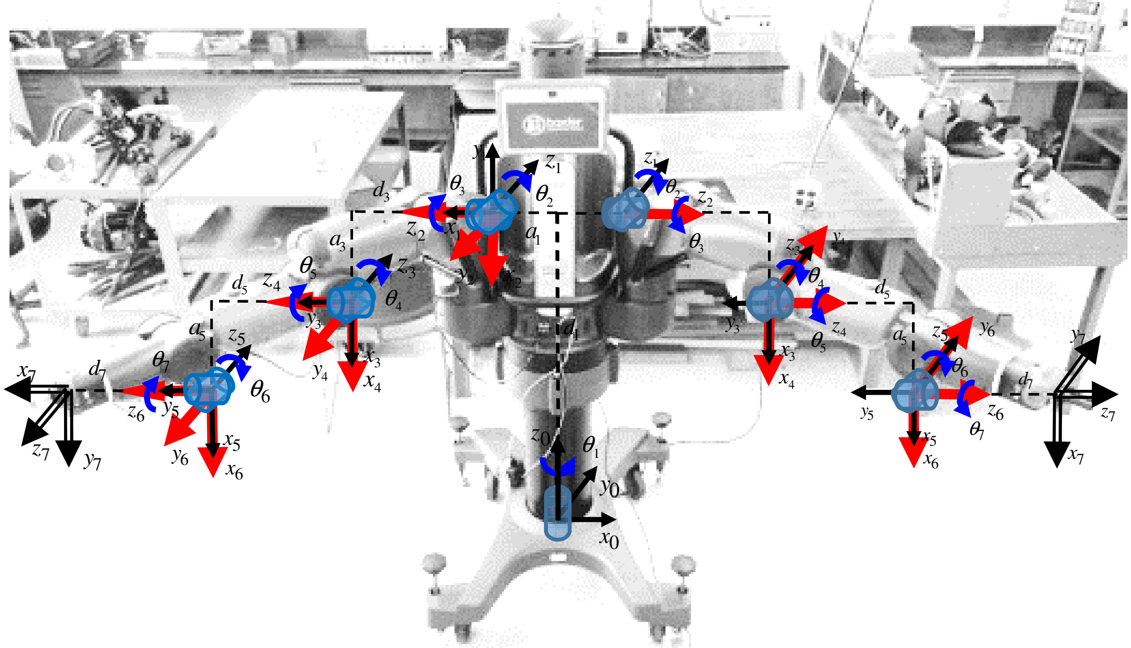


Figure 2: Baxter® kinematic diagram with all coordinate sistems assigned

Step (b) development of Denevet-Hrteberg (D-H) parameters (a_i -link length, d_i-link offset, θ_i -joint angle and α_i^L -twist angle for Left arm, α_i^R - twist angle for Right arm), [7]. See Table 1.

Table 1: Baxter CoBot Denevet-Hrteberg parameters

i	d_i	θ_i	a_i	α_i^L	α_i^R
1	d_1	$\theta_1^L = 0^\circ$, $\theta_1^R = 180^\circ$	a_1	-90°	90°
2	0	$\theta_2^L = 90^\circ$, $\theta_2^R = -90^\circ$	0	90°	-90°
3	d_3	$\theta_3^{LR} = 0^\circ$	a_3	-90°	90°
4	0	$\theta_4^{LR} = 0^\circ$	0	90°	-90°
5	d_5	$\theta_5^{LR} = 0^\circ$	a_5	-90°	90°
6	0	$\theta_6^{LR} = 0^\circ$	0	90°	-90°
7	d_7	$\theta_7^{LR} = 0^\circ$	0	0°	0°

Step (c) To determine the position and orientation of any frame i with respect to frame $i-1$, we use the homogenous transformation matrices ${}^{i-1}A_i$. See Equation 1. Using the D-H parameters from Table 1 and Equation 1 for $i = 1, 2, \ldots 7$, all seven transformation matrices has been calculated.

$$ {}^{i-1}A_i = \begin{bmatrix} \cos\theta_i & -\cos\alpha_i \sin\theta_i & \sin\alpha_i \sin\theta_i & a_i \cos\theta_i \\ \sin\theta_i & \cos\alpha_i \cos\theta_i & -\sin\alpha_i \cos\theta_i & a_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

Step (d) by multiplying all homogeneous transformation matrices from the previous step, staring from Joint 1 and finishing by the end effector, the forward kinematics for Left and Right arms has been calculated. See Equations 2 and 3.

$$ {}^{0}A_{7}^{L} = {}^{0}A_{1}^{L}\ {}^{1}A_{2}^{L}\ {}^{2}A_{3}^{L}\ {}^{3}A_{4}^{L}\ {}^{4}A_{5}^{L}\ {}^{5}A_{6}^{L}\ {}^{6}A_{7}^{L} \tag{2} $$

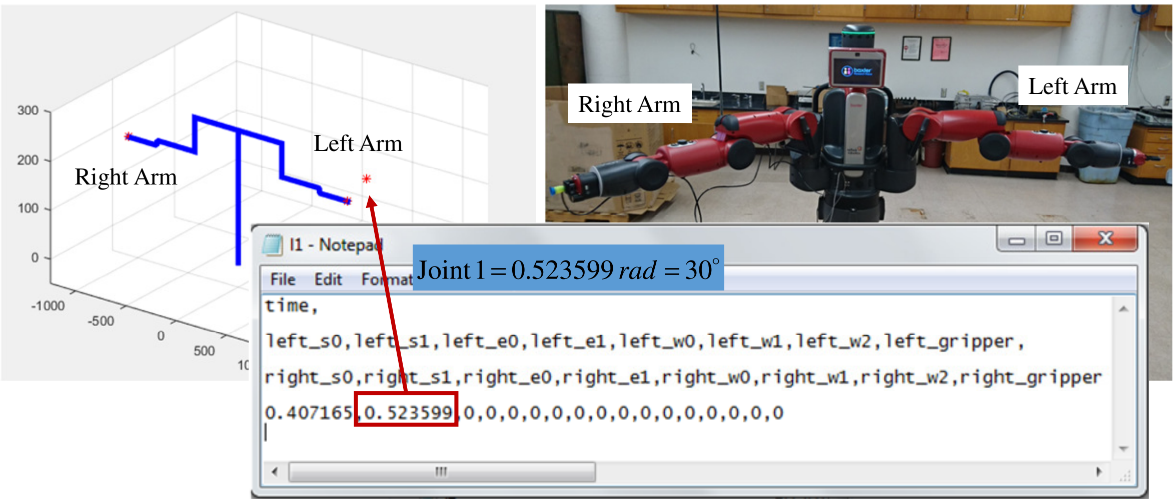
Where ${}^{0}A_{7}^{L}$ represents Left arm end-effector frame 7 posion and orientation with respect to the base frame 0.

$$ {}^{0}A_{7}^{R} = {}^{0}A_{1}^{R}\ {}^{1}A_{2}^{R}\ {}^{2}A_{3}^{R}\ {}^{3}A_{4}^{R}\ {}^{4}A_{5}^{R}\ {}^{5}A_{6}^{R}\ {}^{6}A_{7}^{R} \tag{3} $$

Where ${}^{0}A_{7}^{R}$ represents Right arm end-effector frame 7 posion and orientation with respect to the base frame 0.

Step (e) using Matlab tools, different end-effector positons have been calculated for selected joint angles. In this step students can visualize CoBot kinematic equations. Two points are used to illustrate the procedure and imrtance of the module.

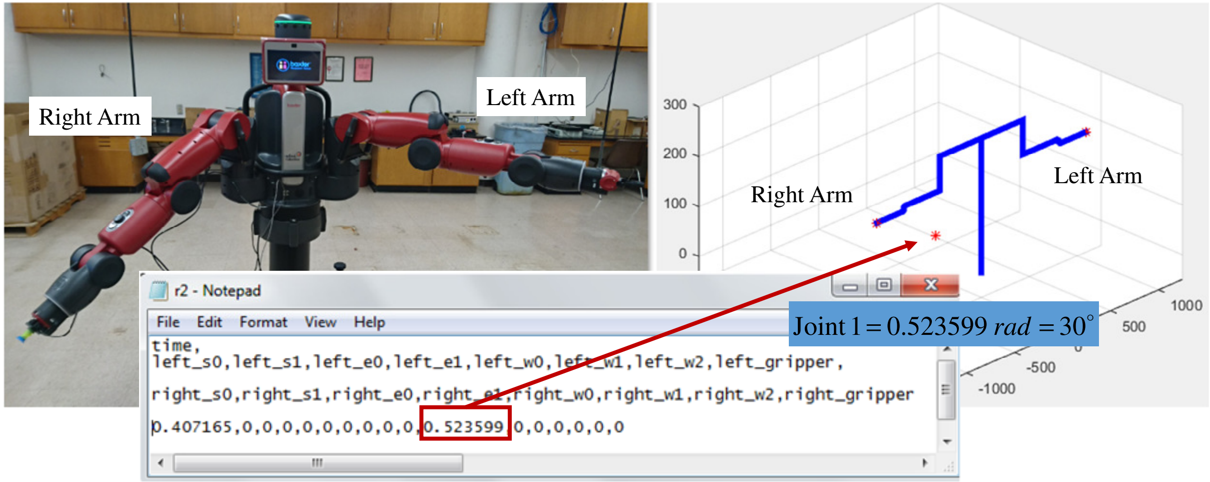
The Left Arm Joint 1 is moved for 30° (0.523599 *radians*) and its posion is calculated and visualised using Matlab. See Figure 3.



```
time,
left_s0,left_s1,left_e0,left_e1,left_w0,left_w1,left_w2,left_gripper,
right_s0,right_s1,right_e0,right_e1,right_w0,right_w1,right_w2,right_gripper
0.407165,0.523599,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

Figure 3: Baxter® Left Arm Joint 1 pozition calculation using Matlab

Similarly, the Right Arm Joint 1 is moved for 30° (0.523599 *radians*) and its posion is calculated and visualised using Matlab. See Figure 4.



```
time,
left_s0,left_s1,left_e0,left_e1,left_w0,left_w1,left_w2,left_gripper,
right_s0,right_s1,right_e0,right_e1,right_w0,right_w1,right_w2,right_gripper
0.407165,0,0,0,0,0,0,0,0,0,0.523599,0,0,0,0,0,0
```

Figure4: Baxter® Right Arm Joint 1 pozition calculation using Matlab

Baxter Kinematic Module Integation in Current Robotics and Mechatronics Courses

The Baxter Kinematic Module has been developed base on the two courses learning objectives. The goal is to use and reuse the same module in different courses. The success of the module integration is shown trough Mechatronic and Industrial Robotic courses objective satisfaction.

Learning Objectives For the Robotic Course

The proposed Learning Objectives for the Indutrial Robotic Course are presented in Table 2. The integrated CoBot module can be used for almost all litsed objectives.

Table 2: CoBot Module stisfactions of Indutrial Robotic Learning Objectives

Industrial Robotics Course Learning Objective		**Industrial Robots**	**CoBots**
1.	Determine different type of industrial robots and their applications.	√	√
2.	Perform mathematical analysis of objects position and orientation in space using homogeneous transformation matrix.	√	√
3.	Mathematical modeling of robot kinematic structure using Denavit-Hartenberg representation.	√	√
4.	Solving the direct kinematic problem for multi DOF kinematic structures with different type of joints.	√	√
5.	Solving the inverse kinematic problem using analytical and geometric approaches applied for multi DOF manipulators.	√	*Not applicable now because of complexity*
6.	Use different methods to calculate the Jacobian, singularities, velocities and static forces for multi DOF kinematic structures.	√	√
7.	Apply computer simulation and off-line programming software, such as Workspace LT.	√	*Currently this is not possible*
8.	Evaluate safety issues for robot workspace layout design (collision detection, path generation, robot Workenvelope generation, etc.).	√	√
9.	Communicate effectively in oral and written formats.	√	√
10.	Select industrial robotic problem, solve it using the robotic theory, prepare engineering report and present.	√	√

Learning Objectives For the Mechatronic Course

The proposed Learning Objectives For the Mechatronic Course are presented in Table 3. The integrated CoBot module can be used for almost all litsed objectives.

Table 3: CoBot Module stisfactions of Mechatronic Learning Objectives

Mechatronics Course Learning Objective		Industrial Robots	CoBots
1.	Design mechatronic system and its primary elements	√	√
2.	Simulate movement of mechanisms in computer aided modelling	√	√
3.	Model different components used in the mechatronic system design	√	√
4.	Control different actuation systems used in mechatronic systems	√	√
5.	Practice basic serial communication and interfacing of electrical control elements	√	√
6.	Program microcontroller and collect data from sensors and control actuators	√	√

Advantages of Integrating Collaborative Robots in Engineering Curiculum

The importance of integrating collaborative robotics in our classes is highlighted in the literature, [8]. In the presented courses above, we summarize the following significates:

- Utilizing the collaborative robotic module in the existing courses can deliver a higher learning experience for our students enabling them to further themselves professionally post-education.
- The collaborative robotic module is flexible and adoptable to be implemented in other engineering courses.
- Using collaborative robot in a safe educational environment students get a more hands on experience and researchers can interact on a higher level with their research.
- Collaborative robots for education are extremely adaptable, they can be used across departments and across functions, from teaching to outreach.
- We use Baxter to provide a teaching platform for the next generation of robotic engineers.

Conclusion

Cobot's technology has been experiencing strong growth in different areas such as ground transportation, food-processing industry, car manufacturing, and naval or aeronautical engineering. In response to the new technology, we developed CoBots learning module which will be integrated in the current robotics and mechatronics courses. The learning module has been developed using Collaborative robot Baxter, robot kinematic theory and Matlab tools. This module utilize theory and hands-on practice to integrate and visualized complex math and physics phenomena. Through the validation and visualization of the kinematic equations, students will be able to connect the robotic and mechatronic theory with different applications using the latest technology.

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Biographies

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OTILIA POPESCU is currently an Assistant Professor in the Department of Engineering Technology, Old Dominion University in Norfolk, Virginia. She received the Engineering Diploma and M.S. degree from the Polytechnic Institute of Bucharest, Romania, and the PhD degree from Rutgers University, all in Electrical and Computer Engineering. In the past she has worked for the University of Texas at Dallas, University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest. Her research interests are in the general areas of communication systems, control theory, and signal processing.