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Conference Paper · June 2018

DOI: 10.1109/TAEE.2018.8476000

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Stirring Up the Learning to Program Robotic Arms Through the Generation of Student Handwriting

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***Abstract*—The use of robotics arms provides students several advantages in the teaching and learning process, compared to methods based on simulation programs. Moreover, programming the robotic arm to imitate a human action previously carried out by the students, makes them to have a better personal satisfaction. Following up this idea, a lab session has been designed and tested by the authors. It is composed by the following phases: Students first register their personal handwriting on a digitizing tablet. Next, they develop a program to make that a commercial robot writes such piece of handwriting. Then, the commercial robotic arm produce such piece of handwriting on a digitizing tablet. Finally, a comparison between the original handwriting and the one made by the robot is worked out. To evaluate the success of the proposed lab session, a survey was issued to students who followed the course in robotics last semester with encouraging resuts.**

***Index Terms*—Robotics, coordinate frames, lab session, handwriting.**

I. Introduction

Programming robots is crucial subject in several degrees related to the engineering. This subject is focused on providing the principles and applications of robotic systems to students. As part of the skills during the course, it is assumed that the students should be able to acquire the necessary knowledge to determine both the position and orientation of the robots. According to [1] [2], the motivation in the learning and teaching process is necessary for an agile development of the skills.

In this paper we propose a lab session for programming robotic arms. Our main contribution is twofold:

- The use of a real robotic arm against the use of virtual simulators. This allows the student to transfer the theoretical concepts learned in class to a real work environment.
- To encourage motivation, the ultimate goal of the practice is to solve a problem: the generation of a handwritten text with the student's own letter.

To satisfy both contributions, in the proposed lab session, the student first produce a personal piece of handwriting on a digitizing tablet. Next, they are supposed to program the robot in order to execute such piece of handwriting by using the file generated by the tablet as input. Later, the robot writes the programmed piece of handwriting while it is registered on the same digitizing tablet, which is located in the robotic writing area, as it is shown in Figure 1. Finally, the original handwriting and the one made by the robot are compared giving a measure of similarity.

Fig. 1: Example of the robot writing in a digital tablet

With this lab session, students work on the skills related to the position and orientation of coordinate frames. Also, they will work on programming skills since they have to code the required program by manipulating the robotic arm. Beyond the designing of the robot program, student finally can quantify the quality of their performance through qualitative measure and by a visual inspection of the robot handwriting.

This paper is organized as follows. Section 2 explains the basic tools to define position and orientation, as well as for programming a robotic arm. Section 3 shows the student's handwriting record. Section 4 shows a pilot practice conducted in the laboratory. Finally, the article closes with the discussion and conclusions in Section 5.

II. Programming the robotic arm

In this section, it will be described the methodology to program the ABB IRB 120 commercial robot[1] by using the data acquired by a digitizing tablet.

[1] http://new.abb.com/products/robotics/es/robots-industriales/irb-120

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A. Representation of the pose of two coordinate frames

In robotics and other fields of science, the combination of position and orientation is referred to as the pose of an object. To represent the pose of two coordinate frames (CF) the homogeneous transformation matrices are widely used [3], [4].

Figure 2 illustrates the pose of the coordinate frame $\{S_1\}$ related to the coordinate frame $\{S_0\}$.

To know their mathematical relationship, a homogeneous transformation matrix such the one shown is used (1).

$$^{0}T_1 = \begin{pmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

The homogeneous transformation matrix $^{0}T_1$ relates the coordinate frame $\{S_1\}$ to the coordinate frame $\{S_0\}$. This matrix provides the relative position of CF $\{S_1\}$ with respect to $\{S_0\}$ and also the orientation of each of its axes. The direction of the axis $\mathbf{i}_u$ of the coordinate frame $\{S_1\}$ is given by the direction vector $\mathbf{n} = (n_x, n_y, n_z)$, that of the axis $\mathbf{j}_v$ by the vector $\mathbf{o}$ and that of the axis $\mathbf{k}_w$ by the vector $\mathbf{a}$. These three vectors are unit-module vectors and form an orthonormal matrix. On the other hand, the vector $\mathbf{p}$ indicates the position of the system $\{S_1\}$ with respect to $\{S_0\}$.

Another way to represent the orientation of the coordinate frame $\{S_1\}$ with respect to $\{S_0\}$ is through the quaternions. In a quaternion, the orientation of the system $\{S_1\}$ can be obtained by rotating the coordinate frame $\{S_0\}$ an angle θ over a vector $\mathbf{v}$. This is the preferred method to represent the orientation for several robots manufacturers and for the ABB robots as well. A quaternion has four components related to the vector $\mathbf{v}$ and the angle θ, with the following equation:

$$Q = rot(\mathbf{v}, \theta) = \left(cos\left(\frac{\theta}{2}\right), \mathbf{v}sin\left(\frac{\theta}{2}\right) \right) \quad (2)$$

Students have the necessary tools to convert a quaternion to a homogenous transformation matrix and vice versa.

B. Coordinate frames

It is essential to define the appropriate coordinate frames in order to program the robot to make an action, like the handwriting.

The coordinate frames used in this session are shown in Figure 3. On the one hand, $\{S_T\}$ refers to the coordinate frame of the tablet, all sampling points generated by the digital tablet are referred to this CF. On the other hand, $\{S_R\}$ denotes the CF of the base of the robot, all sampling points that are going to be drawn by the robot have to be referred to it. Finally, the CF of the pen $\{S_p\}$ indicates its pose.

The pose of $\{S_p\}$ with respect to the CF of the tablet $\{S_T\}$ is given by the on-line handwriting. Moreover, the pose of $\{S_p\}$ with respect to $\{S_R\}$ represents the desired pose of the pen with respect to the base of the robot.

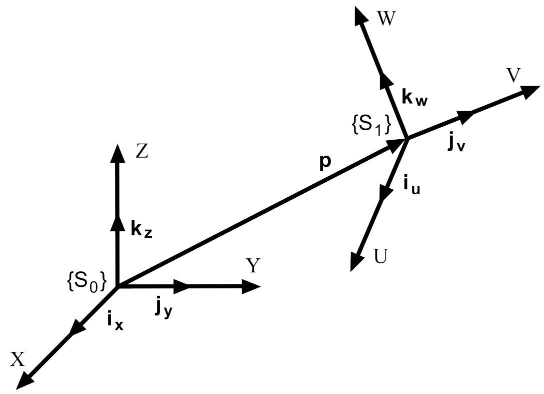


Fig. 2: Coordinate frames $\{S_0\}$ and $\{S_1\}$

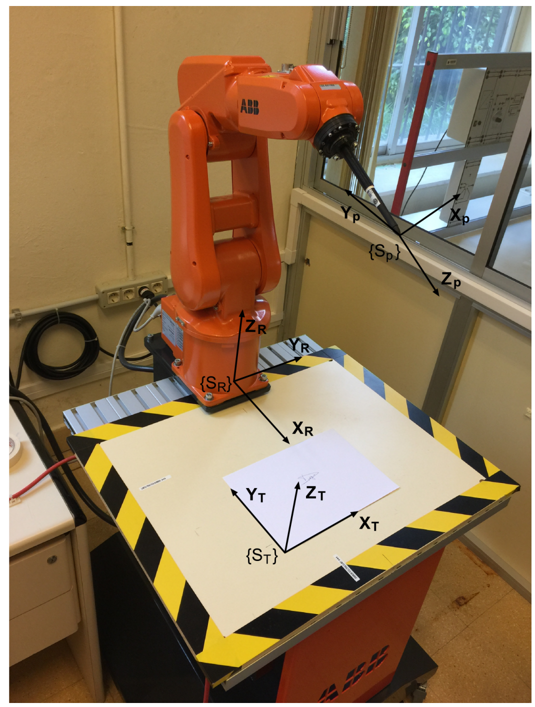


Fig. 3: Coordinate frames assigned to robot, tablet and pen

The homogeneous transformation matrix that relates the CF of the tablet $\{S_T\}$ to the base of the robot $\{S_R\}$ is constant, and it is given by:

$$^{R}T_T = \begin{pmatrix} 0 & -1 & 0 & p_{Tx} \\ 1 & 0 & 0 & p_{Ty} \\ 0 & 0 & 1 & p_{Tz} \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (3)$$

Where (p_{Tx}, p_{Ty}, p_{Tz}) represent the position of the CF of the tablet $\{S_T\}$ with respect to the CF of the base of the robot $\{S_R\}$.

With the data of the handwriting generated by the tablet and the equations that will be deduced later, the matrix $^{T}T_p$ can be calculated for each point. Such matrix relates the pose of each point that was written in the tablet to the CF $\{S_T\}$. This

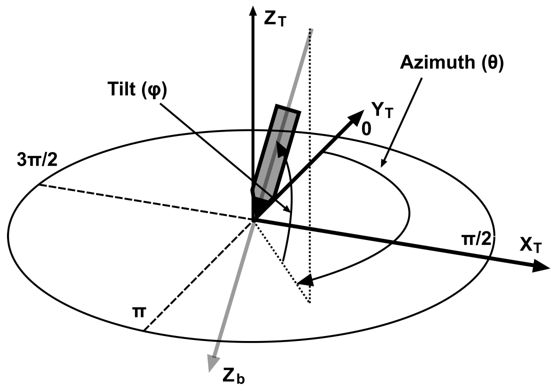


Fig. 4: Orientation of the pen respect to $\{S_T\}$

way, it can be calculated the matrix referred to the base of the robot $\{S_R\}$ for each point using the equation,

$$^{R}T_p = {}^{R}T_T{}^{T}T_p \tag{4}$$

This matrix will be used to generate the code to be programmed into the robot to reproduce a human handwriting

C. Pose of the pen

The information provided by the digital tablet can be considered as the coordinates of the point in p_x and p_y and whether or not it touches the paper, that is, in some way the coordinate p_z. The digital tablet also provides the orientation in azimuth (θ) and tilt (φ) format. Therefore, each point of the tablet has the following information:

$$p_p\left(i\right) = \left(p_x, p_y, p_z, \theta, \varphi\right) \tag{5}$$

This point is referred to the CF $\{S_T\}$, as shown in Figure 4. The first step is to transform each point from the tablet format to the homogenous transformation matrix format. For this purpose, the position is given by p_x, p_y and p_z, and for the orientation the procedure is that by means of turns, the $\mathbf{Z}_T$ axis must fit the $\mathbf{Z}_p$ axis.

Analyzing the Figure 4, it is observed that by turning the coordinate frame $\{S_T\}$ an angle $-\left(\theta - \frac{\pi}{2}\right)$ on the $\mathbf{Z}_T$ axis and then rotating an angle $-\left(\frac{\pi}{2} + \varphi\right)$ on the resulting $\mathbf{Y}_T$ axis, the objective is achieved. Multiplying this matrix and the matrix (3), that relates the tablet to the base of the robot, it is obtained the homogeneous transformation matrix (6) for each point, which relates the tip of the pen to the base of the robot, and where $c(x) = cos(x)$ and $s(x) = sin(x)$

$$^{R}T_p\left(i\right) =$$

$$\begin{pmatrix} c\left(\theta\right)s\left(\varphi\right) & -s\left(\theta\right) & c\left(\theta\right)c\left(\varphi\right) & p_{Tx} - p_y \\ -s\left(\theta\right)s\left(\varphi\right) & -c\left(\theta\right) & -s\left(\theta\right)c\left(\varphi\right) & p_{Ty} + p_x \\ c\left(\varphi\right) & 0 & -s\left(\varphi\right) & p_{Tz} + p_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{6}$$

The students must obtain the orientation of the pen in the quaternion format by using the matrix 6. Therefore, they can generate their own code, because for each point in the homogeneous transformation matrix format, they can generate their corresponding point referred to the base of the robot. Similarly, they can proceed with the orientation of the pen in the quaternion format. That way the format of each point is obtained by the following expression:

$$^{R}p_p\left(i\right) = \left(\left[p_{ix}, p_{iy}, p_{iz}\right], \left[q_{i1}, q_{i2}, q_{i3}, q_{i4}\right]\right) \tag{7}$$

D. Programming the robot

The handwriting is programmed in the robot by using the Robotstudio software for ABB robots. This software use an own programming language named RAPID language [5]. Because the sampling points in which the handwriting is divided are very close to each other, they were joined using straight lines. It is worthy pointing out that it can be set the robot to joint the points in circular trajectories. Circular trajectories would be useful for joining more separated sampling points in the handwriting, for example.

The RAPID has a command for writing straight lines that has the following format:

MoveL $[[p_x, p_y, p_z]$,$[q_1, q_2, q_3, q_4]$,$[-1, 0, 0, 0]$, [9E9, 9E9, 9E9, 9E9, 9E9, 9E9]], v60, fine, MyPen\WObj:=wobj0;

The most important parameters are the following; the others will be left as they are:

- $[p_x, p_y, p_z]$: target point, (the origin point is where the tip of the pen is located).
- $[q_1, q_2, q_3, q_4]$: Orientation of the pen in quaternion format.
- v60: indicates the speed in this case indicates 60 mm / s.
- fine: indicates that the end point is reached with maximum precision.
- MyPen\WObj: = wobj0: Indicates the tool used, in the case studied is the pen.

Therefore the student should carry out a program, having all sampling points of the handwriting in the format given by (7). Then, they should write the required code to generate the straight lines in RAPID format. Once this file is generated, it can be downloaded into the robot and can be executed. The robot, therefore, execute the signature with the pen on the tablet. Once the signature is made, the signature file generated by the tablet will be stored in the computer.

III. Digitalization of the Handwriting Using a Tablet

To acquire handwriting, current technology allows, among others, two well-known and accepted methods. On the one hand, through a paper and a pen and, on the other hand, through a digital tablet. The first case is called static handwriting and the second dynamic handwriting.

Static writing is more used in our society than dynamic writing. However, both are equally accepted. In general terms, people sign indistinctly both on paper (e.g. classroom assistance) and on a digital tablet (e.g. validation of a credit card during a commercial transaction).

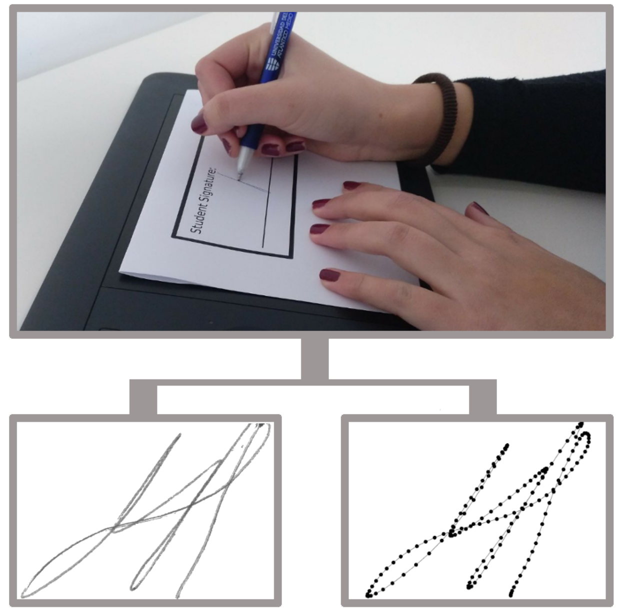
From the computational point of view, the static handwriting is processed in a computer as an image with different intensity levels of color because the inked pen. Instead, dynamic handwriting consists of signals, typically of trajectory and pressure ordered according to the executed handwriting. These signals allow to know intrinsic properties to the writer, such as the duration of his handwriting, the writer's kinematics (e.g., his speed and acceleration) or the different levels of pressure throughout his handwriting. In addition, it allows us to reproduce the exact order in which the writing was made.

In our experiments, we have used handwriting signatures. The signature is a personal characteristic that is learned and practiced throughout life [6]. As such, it has been considered that the use of students handwriting signature can encourage the motivation and engagement for programming robot.

To digitize the handwriting signature, this paper proposes a method that attends the acquisition of both static and dynamic handwriting. To do this, a WACOM digital tablet is used, specifically the WACOM Intuos pro model, which allows to acquire both static and dynamic handwriting at the same time.

As most students are accustomed to signing with pen on paper, in this work an ink pen capable of communicating the dynamics of writing to a digital tablet has been used. Figure 5 shows a paper that has been placed on the digital tablet for the student to sign. The result is a static signature and a dynamic signature at the same time.

Finally, it is worth mentioning that the digitizing tablet gives the information of the pen in space, that is, its position on a writing plane and its orientation in terms of azimuth and tilt. This information will be used to programming the robotic arm.



Static handwriting   Dynamic handwriting

Fig. 5: Handwriting acquisition in a digital tablet. In each execution, we can acquire a static and a dynamic version of the student signature simultaneously.

IV. Experiments

Several tests were carried out with the ABB-IRB120 robot, available in the laboratory of systems engineering and automatic at the Universidad de Las Palmas de Gran Canaria. In the tests, the generated handwriting consisted in handwriting signatures. For this purpose, human on-line signatures were registered with a digital tablet. Then, the robotic arm was programmed by converting the on-line signatures into a set of robotic coordinates for each signature sampling point, as it was detailed in Section 2. Later, the digital tablet was put on a table, within the writing area of the robot. A blue inked digital pen was installed in the extreme of the robotic arm. Finally, while the robot writes the signatures on the paper, they were stored in a computer. To calculate the similarity between the human and robotic signatures, the Signal-to-noise-Ratio between the trajectories was used according to the following equation, in its discrete form:

$$SNR = 10\log\left\{\frac{\sum_{i=1}^{n}\left[x_{sp}(i)^2 + y_{sp}(i)^2\right]}{\sum_{i=1}^{n}\left[x_{sr}(i)^2 + y_{sr}(i)^2\right]}\right\} \tag{8}$$

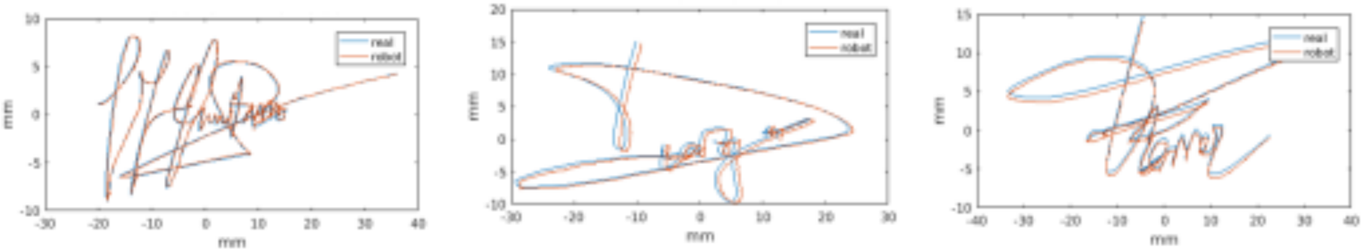
Where the numerator is $x_{sp}(i) = (x_s(i) - \overline{x}_s(i))$ and $y_{sp}(i) = (y_s(i) - \overline{y}_s(i))$. Being $(x_s(i), y_s(i))$ the student's signature's trajectory and $(\overline{x}_s(i), \overline{y}_s(i))$ its average trajectory for the horizontal and vertical axis, respectively. Instead, the denominator is $x_{sr} = (x_s(i) - x_r(i))$ and $y_{sr} = (y_s(i) - y_r(i))$, being $(x_r(i), y_r(i))$ the robot's signature's trajectory, which is evaluated with the SNR. Both pieces of handwriting were interpolated in order to ensure the same number of sampling points n, and, therefore, to make the comparison with the SNR.

On the one hand, all human signature sampling points were converted into robotic parameters, i.e. position and angles, as it is shown in (7). Because the robot tries to reach all sampling points at a low speed, its final trajectories result in stepped trajectories. For this reason, the robotic trajectories were smoother with a low pass filter in order to improve the SNR. In [7] it was studied that to the SNR should be above 15 dB for handwriting recognition purposes. However, for our purposes, the value obtained both visually and numerically satisfies the correct handwriting generation made by the robot.

For a visual validation, Figure 6 shows three signatures made by a human, *real*, and by the robotic arm, *robot*. To quantify a valid SNR for students, we executed several times these three robotic signatures. Then, we compare the SNR of each execution with the human handwriting.

Even though the motors in the robot leads to small noise in the signature trajectories, the narrow margin of SNR confirms the consistency of the robot to generate handwriting. In Figure 7 it is observed the SNR for different repetitions of each signature illustrated in Figure 6.

Finally, we can conclude that students can achieve the maximum punctuation in this session lab, if the final SNR



(a) Real and robotic signature 1 (b) Real and robotic signature 2 (c) Real and robotic signature 3

Fig. 6: Visual comparison between the overlapping of the real and the robotic handwriting signature's trajectories

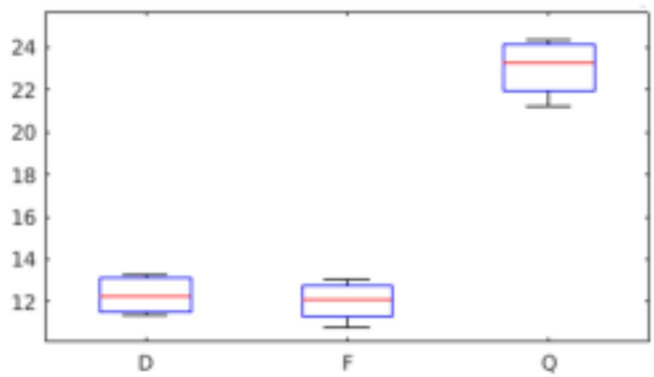


Fig. 7: Quantitative comparison between a real and several repetitions of the robotic signatures. Performance in terms of SNR.

between their handwriting and robot handwriting is above 10 dB of SNR.

V. Survey results: A pilot study

An initial survey was issue to students from the third year, enrolled in the Bachelor degree in industrial electronic and automatic engineering at the University of Las Palmas de Gran Canaria. A total of fifteen student participated in the survey.

These students completed the "control of robots" course last semester. In the lab sessions, each student programmed the robot to draw a technical drawing figure. This session was useful for developing the concepts discussed in this paper as well as to pass the theoretical questions in the exam. Thus, it is expected a meaningful judgment of these students to foresee the success of the novel lab session described in this article. Moreover, since this survey was issued after the students know their final score in the course, they did not feel under pressure to complete it.

It is worthy pointing out that additional learning outcomes will be developed in the proposal novel lab session. For example, while the pen orientation was fixed in previous lab session, the proposal one considers that the pen orientation changes during the handwriting. As this fact implies more effort for the students, it could be a matter of rejection.

The aim pursued for conducting this survey is two fold. On the one hand, to check whether the lab session that the students completed was useful to acquire the competences of the course. On the other hand, to foresee whether the novel lab session described in this article is more appealing to them than the previous one.

The survey was designed in the basis on a seven-grade Likert scale, 1 being "totally disagree" and 7 "totally agree". Obviously, the novel proposal lab session was explained to them before completing the survey. Table I shows our survey questions and results in terms of average and standard deviation.

A. Discussion

Regarding the *Block 1* results, it is observed a positive perception about the learning and skills developed in the previous lab session. The best evaluation is observed in question 1. It is an expected outcome since Q1 is related to the use of the robot.

About *Block 2*, it is clearly observed in Q5 that students prefer that the robot draws something designed by them. Moreover, Q6 suggests that varying the pen orientation when robot writes can lead to a higher motivation. This is probably due to the fact that these students were familiar with this robot. On the other hand, the average of question 4 is slightly higher of question 3. It was expected since the previous lab session did not pay special attention to the orientation of the pen.

Finally, in *Block 3*, respondents believe that a mathematical equation to compare the similarity between the original drawing and the one made by the robot, i.e. SNR, is quite positive, compare to previous method to compare through visual inspection. This is clearly observed in the Q7's score, which is slightly higher than Q6 result. Regarding question 7, the obtained average result is promising. However, in the analysis of original data, we observed that two participants scored this question with 1. This may be produced by the fact that the novel lab session involves more mental effort. As such, it makes the previous lab sessions more comfortable and faster.

To sum up, our novel proposal lab session for programing robots not only was designed for increasing the student motivation, but also for improving the learning processes behind the course. In general, the survey foresees a positive benefits and promising challenges about developing our proposal with future students.

TABLE I: Survey Results

Questions	Average	Standard Deviation
Block 1: Questions related to the previous lab session completed by the student		
Q1: Have you improved your abilities in programming the ABB robot?	6.1	0.99
Q2: Have you gain knowledge about the geometrical relationship among the different coordinate frames?	5.7	1.10
Q3: Do you feel comfortable operating with orientation systems such as quaternions, Euler angles or rotation matrices?	5.5	1.55
Block 2: Questions related to the novel lab session and the expected learning.		
Q4: Do you think that the proposal lab session would make improvements in the acquire knowledge about orientation systems such as quaternions, Euler angles or rotation matrices?	5.9	1.75
Q5: Considering that the robot has to produce a motion, would you prefer programming your own handwriting instead of a technical drawing figure assigned by the professor?.	6.7	0.70
Q6: Do you think it is appropriate for the learning process that the robot varies the orientation of the pen in a way similar to the human handwriting instead of fixing it?	6.0	1.60
Block 3: Questions related to the motivational aspects of the novel lab session.		
Q7: Would you feel pleased to compare the degree of similarity between the drawing made by the robot and the student by a mathematical formula?	6.3	0.98
Q8: Would you feel that the lab sessions will be funnier with the proposal instead of the sessions that you have already completed?	5.8	2.04

VI. Conclusions

In this paper it is proposed an innovative lab session for programming robots. In the proposal, the students interact with a robotic arm because they have to program it to produce their own handwriting. It is expected that the students use different methods to represent the position and orientation of different coordinate frames, that they program a commercial robotic arm and, that they record by means of a digital tablet the original signature and the one made by the robot. Finally, they can check both visually and numerically by means of the SNR the similarity of the signatures made by themselves and by the robot. As a summary, the students can complete many crucial requirements in programming robot course through this novel lab session.

To foresee the acceptation and motivational aspects of this novel lab session, a survey was issued to fifteen students, who completed the control of robot course last semester. They were asked to compare the lab session that they completed and the proposed one. In general terms, the students evaluated positively the fact that the robot could draw what they had previously drawn. They also evaluated accurately that not only a visual comparison of the results was required to compare the robot movement, but also a quantitative method, i.e. the SNR.

In our future works, it is planned to make more human-like the robot handwriting [8]. Currently, the robot tries to reach all ordered sampling points by setting a low velocity. Instead, people use to write fluently and rapid, specially a signature like in our tests.

VII. Acknowledgments

Authors would like to thank José Antonio Santana Segura, laboratory technician at Department of Automatic and Electronic Engineering in Universidad de Las Palmas de Gran Canaria for his support during the experiments with the ABB IRB 120 robot.

This study was funded by the Spanish government's MIMECO TEC2012-38630-C04-02 research project and European Union FEDER program/funds.

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