Secure handwriting using a robot arm for educational purpose

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***Abstract*— As the educational system is growing there is a lot of paperwork to do like completing different types of certificates, or traditional gradebook. The paper presents a different approach to facilitate and secure the writing of certificates or traditional gradebooks. This system uses a robot arm, RV-2AJ, which has a pen attached. The setups are easy to be made because they involve the reading of only three points for calibration which forms a right-angled triangle. After the calibration the robotic arm can write even if the writing surface is on an inclined plane, or the paper is rotated. This system is more secure than the one that uses the ink printer, because the movement of the robot arm to reproduce the font on the paper is unique. Another secure element is the embossing stamp. The embossing stamp is created by changing the pen with a needle. The needle creates small closed holes using a pattern in which the information used for writing is encrypted.**

Keywords—handwriting; robot arm; RV-2AJ; calibration; secure; certificates;

I. INTRODUCTION

Completing official documents may be a difficult task. In the past, certificates were completed using handwriting which requires a good calligraphy and the focus is on not misspelling the words. To handwrite a lot of documents can take a long time. An alternative for this is using a computer and a printer. The text which is written on the documents in the most cases is in a database and with a special software it is easy to print in the blank spaces on the document. This system is mostly used in the Word, because printers are cheaper. The size of most printers is A4, and it can print only on the thin paper. Some documents may need only handwriting to make them unique and printers cannot be used [1]. Since oversized documents cannot be fit into the printer tray, the only option would be a handwriting ones. For those documents we create a handwritten system based on a robotic arm.

The robotic arm is produced by Mitsubishi and is called RV-2AJ. It has 5 degrees of freedom with 5 joints (J1, J2, J3, J5, and J6) and accuracy of 0.01 mm. This type of robot is suitable for handwriting. The problem of handwriting with a robot is difficult because the pen is designed to write using the human hand [2, 3], so for that the human handwriting must be studied, (see example [4-10]).

Handwriting is considered to be unique for each person [4-6], this thing is available for the robotic arm too. We made an experiment and printed the text that was send to the robot. The two texts were different especially on corners, the robot makes round corners. This thing is better to secure the handwriting because not everyone has this type of robot, like in the cases of conventional printers. The robot cannot simulate the exact human movements so the ink deposition will be different [7-10].

For the documents to be more secured the embossing stamp was invented. The difference between the embossing stamp and a conventional one is that the embossing stamp marks the paper in depth, not only on the surface. The robotic arms have the capabilities to move along 3 axes so in function of what tool is installed on gripper it can mill to the paper on different depths.

The structure of the paper is as it follows. Section II presents the Description of the system equipment: Hardware and Software components of the controller, the basic relations for the robot kinematics and the writing instrument. Section III presents the main mathematical information about robot calibration. Finally in Section IV a synthesis about the use of the software and how the certificates are written. The main Conclusions are given in section V.

II. DESCRIPTION OF THE SYSTEM EQUIPMENTS

A. Robot arm's hardware

1. The central part of the system is the RV-2AJ robotic arm (Mitsubishi Co). To work the robot arm needs some external components like: CR1-571 controller, bench work, a computer with dedicated software and access to the school database, and a compressor for the pneumatic gripper.

B. 2. The robot kinematics

The Mathematical Model, the Direct Kinematics Problem and the Inverse Kinematics Problem were developed for this robot to work. Figure 1 is a scale model drawn in Catia and the notation used in equation system are shown (1). To implement the direct problem, an origin of the coordinate system, the point O, must be defined and the position of the end-effecter E must be calculated using the system equations(1),(see example [11]):

$$X = \cos(\theta_1) * [AB * \cos(\theta_2) + BC * \cos(\theta_3) + (CD + DE) * \cos(\theta_4)]$$

$$Y = \sin(\theta_1) * [AB * \cos(\theta_2) + BC * \cos(\theta_3) + (CD + DE) * \cos(\theta_4)]$$

$$Z = OA + AB * \sin(\theta_2) + BC * \sin(\theta_3) + (CD + DE) * \sin(\theta_4) \tag{1}$$

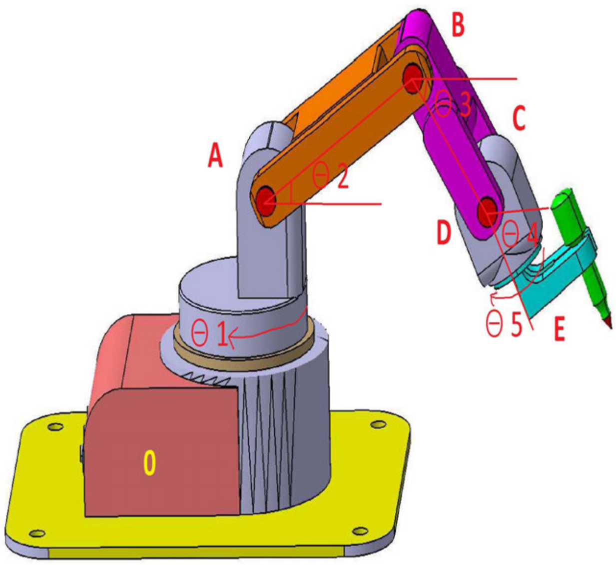

Fig. 1. The Kinematics scheme of RV-2AJ

The inverse kinematics means to calculate joint's angles if the position of end-effector is known. In Figure 2 the kinematic scheme of the inverse problem is shown. The equations system (2) is used to calculate joint's angle (see example [11]).

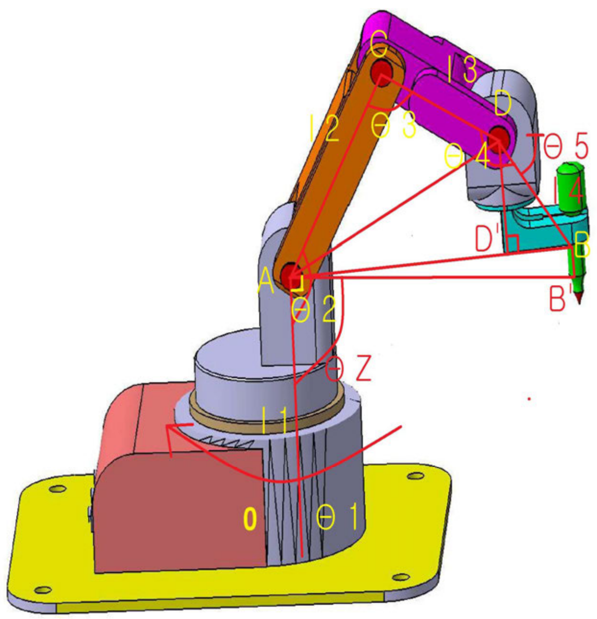

Fig. 2. The Kinematic scheme for invers problem

$$\theta_1^{'} = \arccos\left(\frac{l_2^2 + l_3^2 + AB^2 - 2*AB*l_5*\cos(\theta_5) - l_3^2}{2*l_2*\left(\sqrt{AB^2 + l_5^2 - 2*AB*l_5*\cos(\theta_5)}\right)}\right)$$

$$\theta_2^{'} = \arccos\left(\frac{l_2^2 + l_3^2 - l_5^2 - AB^2 + 2*AB*l_5*\cos(\theta_5)}{2*l_2*l_3}\right)$$

$$\theta_3^{'} = \arccos\left(\frac{l_3^2 + l_5^2 + AB^2 - 2*AB*l_5*\cos(\theta_5) - l_2^2}{2*l_3*\left(\sqrt{AB^2 + l_5^2 - 2*AB*l_5*\cos(\theta_5)}\right)}\right)$$

$$\theta_2 = \theta_Z + \theta_1^{'} + \arcsin\left(\frac{DD'}{AD}\right) \qquad \theta_3 = \theta_2^{'} \tag{2}$$

$$\theta_4 = \theta_3^{'} + (90^o + \theta_5) + \arccos\left(\frac{DD'}{AD}\right)$$

$$\theta_1 = arctg\left(\frac{Y}{X}\right)$$

In order to handwrite with this robot arm we have two opportunities: using the system equations (2) and calculate the joint's angles for each point (point E) of the drawing, or using the controller embedded functions that allow the end-effector to a point in space definite by Cartesian coordinates. The first method is a difficult task because for a single point E there are an infinite number of combinations of joint movements and these involve an algorithm to choose the best combination. This aspect will be the subject for a future research. For this experiment we use the controller function that moves the end-effector in Cartesian coordinate. The unit size used is 1mm.

C. *The writing instrument*

The writing instrument is shown in Figure 3 and is actually a ballpoint pen. Inside the pen there is a spring which allows the tip to move up and down (10mm) along the z-axis, in this way the dispersion of the ink is uniform.

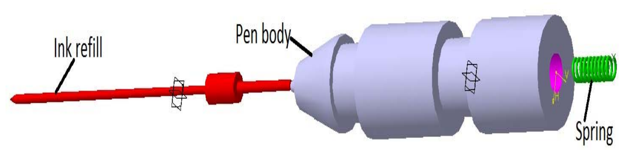

Fig. 3. The exploded version of pen

Fig. 4. The real pen used

The real pen, shown in Figure 4, has a metal cylinder, for protection against the powerful gripper of the robot. This pen is used only for testing. For writing real certificates a special ruling pen will be used like the one used by the architects. This pen has a permanent ink which does not deteriorate in time.

For the embossing stamp a needle is used which makes small holes in the paper. The pattern of the holes will be discussed in section IV.

III. MATHEMATICAL CONCEPTS FOR THE ROBOT CALIBRATION

To achieve the desired accuracy, the robot arm must be calibrated. The main calibration is made with robot software. Each joint must be put on 0 degree position. To find the 0 degree position the (3) is used, for each joint, in which: C is the 0 degree position minh and maxh is the hardware operating range and min and max are the software operating range from the datasheet.

$$C = \frac{\min h + \max h - \min - \max}{2} \quad (3)$$

After the main calibration the xyz plane is parallel to the robot chassis, Z- axis is perpendicular to the chassis, X- axis is parallel with the shoulder shift and Y- axis is perpendicular to shoulder shift. If the writing stand is not in the same plane with the robot plan then the pen will penetrate the paper, or will be above the paper without touching it. To resolve this issue a software calibration must be done, which means to recalculate all the coordinates that are sent to robot so as the pen to touch the paper with the same force (see example [12]). In order to do this the plane of the writing stand must be known, by manual movement the arm and reading the coordinates of three points from the writing stand. In Figure 5 it is shown how the points must be read. The black axis is the robot plane, and the red one is the writing plane. After the reading points two types of calibration are needed: one for the X, Y axis (the rotation) and one for Z axis in which for each point (x, y) is calculate the z value in order the pen to touch the paper.

For the rotation calibration it must determine the rotation angle θ. For accuracy θ can be average of a and b. In (4) it is shown how θ is determined. The new x, y coordinates of the rotated point is defined by the system equations in (5). For easy calculations point P is chosen to be the origin of the system, so *P(x,y,z)* will become *P(0,0,0)*, *P1(x1,y1,z1)* becomes *P1(x-x1,y-y1,z-z1)* and *P2(x2,y2,z2)* becomes *P2(x-x2,y-y2,z-z2)*.

$$\theta = \frac{arctg(\frac{y1}{x1}) + arctg(\frac{x2}{y2})}{2} \quad (4)$$

$$\begin{aligned} x^{'} &= x \cdot \cos(\theta - 90) - y \cdot \sin(\theta - 90) \\ y^{'} &= x \cdot \sin(\theta - 90) + y \cdot \cos(\theta - 90) \end{aligned} \quad (5)$$

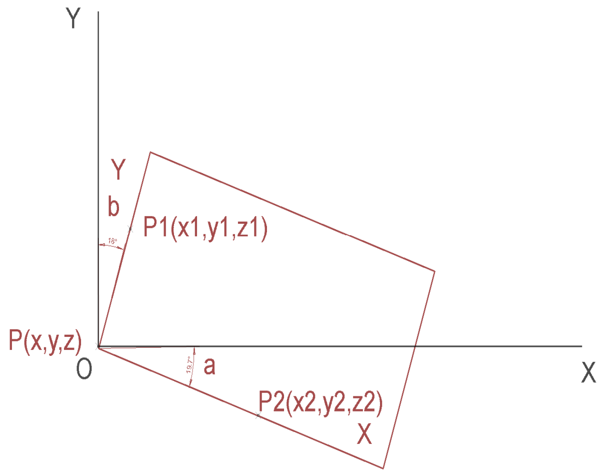

Fig. 5. The writing plan calibration points

The calibration for the Z axis is shown in Figure 6. The robot system of coordinate is *X, Y, Z*, and for the writing plane the system is *X1, Y1, Z1*. The difference between these two planes is that the Z coordinate, on *X, Y, Z* plane Z=0, and on *X1, Y1, Z1*, Z1 coordinate must be calculated. After the reading of the three calibration points P, P1, P2 (these points are on the writing plane) we need to determine the writing plane equation (6). Let's assume that P3(x3, y3, z3) is the pen coordinate on the writing plane that must be calculated.

$$ax + by + cz + d = 0 \quad (6)$$

The components of the unit normal vector $\hat{n} = (n_x, n_y, n_z)$ must be defined in (7).

$$\begin{aligned} n_x &= \frac{a}{\sqrt{a^2 + b^2 + c^2}} \\ n_y &= \frac{b}{\sqrt{a^2 + b^2 + c^2}} \\ n_z &= \frac{c}{\sqrt{a^2 + b^2 + c^2}} \\ p &= \frac{d}{\sqrt{a^2 + b^2 + c^2}} \end{aligned} \quad (7)$$

The Hessian normal form of the plane (8), in which x is an ordinary point of the plane, $\hat{n}$ is the unit normal vector and p is the plane constant.

$$\hat{n}x = -p \quad (8)$$

Matlab has a function which determines the $\hat{n}$ vector from the given three points. After the $\hat{n}$ vector is known the z coordinate of P3 can be determined using (9).

$$z3 = \frac{-n_x x3 - n_y y3}{n_z} \tag{9}$$

After we made the z axis correction if we take two points and draw a line between them, the distance will be higher, in that case the writing plane is parallel with the plane of the robot. This is happening because, the pen is not perpendicular to the writing plane, so we have to find point P4(x4, y4, 0) on the robot plane which is the intersection of the robot plane with line from point P3 and $\hat{n}$ vector. In (10) is the equation of the line which has a point and a direction.

$$\frac{x - x_0}{n_x} = \frac{y - y_0}{n_y} = \frac{z - z_0}{n_z} \tag{10}$$

In our case we use (10) with z=0, in order to determine point P4(x4, y4, 0) from point P3(x3, y3, z3) as shown in (11).

$$x4 = \frac{-z3 \cdot n_x + x3 \cdot n_z}{n_z}$$
$$y4 = \frac{-z3 \cdot n_y + x3 \cdot n_z}{n_z} \tag{11}$$

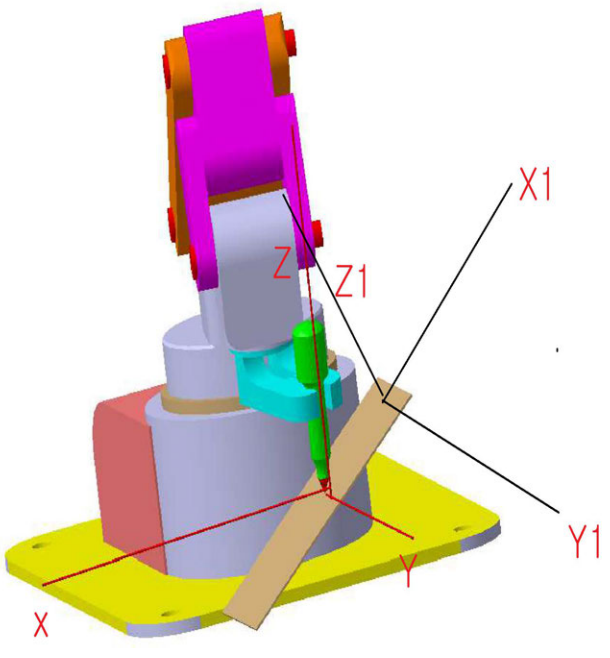

Fig. 6. The writing plane Z axis calibrations

IV. SOFTWARE DESCRIPTION

A cad soft was used to design the text used in the robot handwriting called *Eagle*. Eagle is designed for PCB production, so it has the ability to work with CNC machines, by generating different types of files used by the most of the CNC. In our cases we use PS (Post Script). In Eagle a template picture of the certificate is inserted, Figure 7, and the blank spaces are completed with text using a different layer. Then the PS file for the text layer is generated from the cam processor menu. The main advantage of this type of software is that the dimensions are in *mm*, so the text size for all fonts on the paper will be the same.

Fig. 7. Example of a blank certificate (in Romanian).

The PS file is converted by a Matlab script to Melfa IV language that is known by the robot controller. In this script those three points used for calibration are inserted.

Figure 8 is the dataflow of the Matlab algorithm. The script calculates the rotation angle and the writing plane equation. It opens the PS file and reads each line.

If the line is a line coordinate then it writes in the output file the command for the robot to move between two points. It also calculates the coordinates of the points so as the pen to touch the paper.

If the line is a circle coordinate then it writes in the output file the command for the robot to draw a circle made from 3 points. The program must calculate those 3 points because in the PS file the circle is determined by an origin and the radius; also the program calculates the points' coordinates as the pen to touch the paper.

If the line is an arch coordinate then it writes in the output file the command for the robot to draw an arch made from 3 points. It has to calculate those 3 points because in the PS file the arch is determined by an origin, the radius, start angle and stop angle. It also calculates the points' coordinates so as the pen to touch the paper.

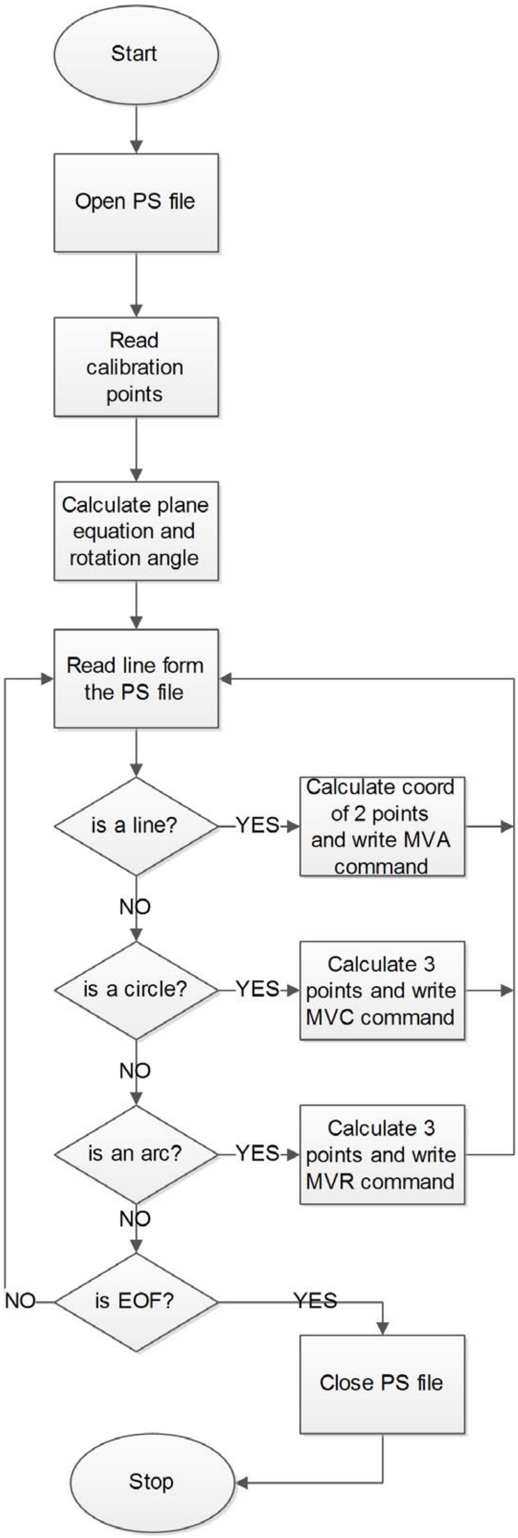

Fig. 8. The Matlab script algorithm

The script file has a separate section in which the embossing stamp is generated. The algorithm used transforms the name written on the certificate in an ASCII Code and then each letter in a binary code. A matrix results in which a line is a letter. For making the embossing stamp on paper the robot will perforate the paper, using a needle, with one hole for *0* and two holes for *1*. Table I illustrates as an example the name *Marius Crainic* in the binary code and in the stamp code.

TABLE I ENCRYPTION OF THE NAME

Binary Code	Stamp code
01100011	.::...::
01101001	.::.:..:
01101110	.::.:::.
01101001	.::.:..:
01100001	.::....:
01110010	.:::..:.
01000011	.:....::
00100000	..:.....
01110011	.:::..::
01110101	.:::.:.:
01101001	.::.:..:
01110010	.:::..:.
01100001	.::....:
01001101	.:..::.:

In Figure 9 the embossing stamp is illustrate. It was written from bottom to top.

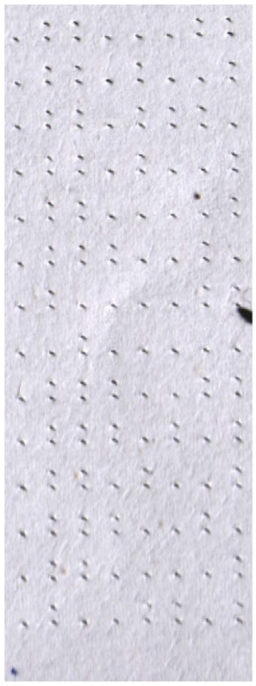

Fig. 9. The embossing stamp

In Figure 10 the certificate which has been written is shown. On the bottom of page the embossing stamp can be seen.

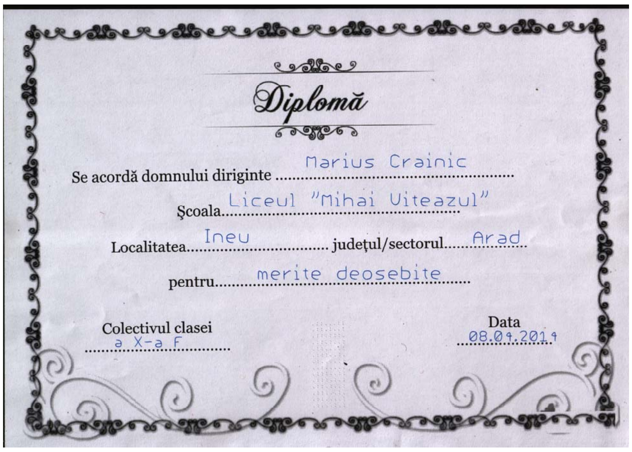

Fig. 10. The printed certificate (in Romania)

V. Conclusion

The paper has presented another type of handwriting using a robotic arm. In order to write the pen must gently touch the paper. For this thing a calibration was made. So by reading 3 points from the writing plane the equation of the plane can be determined and the Z axis value calculated in order to compensate the writing plane tilt. Another compensation is if the paper is rotated at an angle. This compensation can be done from the same 3 points compensation. This type of calibration is faster than if the writing plane is adjusted with screws in order to be in same plane with robot plane, because we don't have to screw the screws.

In Figure 11 we draw a bicycle to see if the implementation of line, circle and arch functions work properly and for educational purpose too.

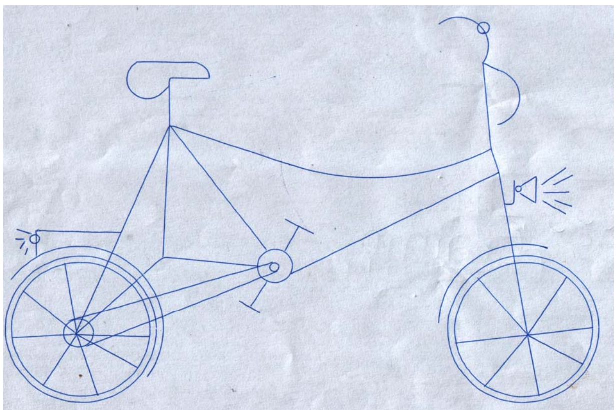

Fig. 11. The drawing of a bicycle

This type of handwriting is hard to copy, because the movement of the robot is unique, the robot is too expensive for average people and it has an embossing stamp which is impossible to make without robot arm. In Table I we present a simple example of encrypted data in the embossing stamp, but a strong encryption can be done with different algorithms.

This kind of writing is useful for educational purpose too. The students can learn how to calibrate the robot, how to work with Matlab and implement theoretical concepts in practice.

As a future improvement a milling machine can be put in the gripper and a 3D sculpture can be obtained, like PCB production, or gearboxes.

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