CONTROL AND ACTUATION OF A PARALLEL ROBOT WITH THREE DEGREES OF FREEDOM

Florin COVACIU, Laura-Nicoleta COVACIU

Abstract: *This paper presents the control and actuation system of a parallel robot with three degrees of freedom. To control this parallel robotic system, a user interface has been developed through which the user can interact with the robot. Through this interface, the robot's servomotors can be individually controlled by means of sliders. During the control we can see the current positions of the three servomotors on the user interface because these servomotors are equipped with absolute encoders. After trajectory of points have been made for manipulating objects via the gripper, these points were stored, and via five buttons on the user interface the parallel robot can manipulate objects by taking them to five predefined points.*
Key words: *parallel robot, control and actuation, servomotors, pick and place, microcontroller.*

1. INTRODUCTION

An advanced industrialized society requires a flexible automation of production processes, in which robots play a key role. Robotics transcends the boundaries of traditional engineering, being a field of modern engineering. To build a robot we need more knowledge, such as: mechanical engineering, electrical engineering, computer science and mathematics [1, 2].

Robots are classified into serial robots that have open loop kinematic chains and parallel robots that have closed loop kinematic chains. By integrating two previous technologies, the robot was born, namely numerically controlled milling machines and teleoperators, which were used in World War II to clean hazardous materials. Serial and parallel manipulators are increasingly appreciated through applications in the fields of pick and place robots, production, medical equipment, space, and so on [3].

The paper is organized as follow: Section 2 present related work. Section 3 presents the control and actuation system continuing with the user interface in section 4, followed by conclusions and references.

2. RELATED WORK

In recent days, the parallel robot has more and more applications due to its precision, speed and high loading capacity. While the serial robot has a console structure that makes it susceptible to bending at high loads and, also at high vibrations at high speeds. In [4] the authors propose the construction of a prototype of Delta robot with 4 degrees of freedom. This prototype is built using the development platform with the STM32 processor. In [5] a new control architecture for a parallel HEXA robot with six degrees of freedom is presented. To allow real-time control for complex trajectories the control algorithm was implemented directly in the robot's PLC.

Wu et al proposes an optimal control for the uncertain Delta robot. A theoretical approach is creatively used to describe the uncertainty of the system using fuzzy rule sets [6]. In [7] is described the design and manufacture of a Delta robot with 3 degrees of freedom. The robotic system was designed using the Fusion 360 program, and the components of the robotic system were manufactured using the 3D printer.

In [8] the authors propose in a competition dedicated to robots the design and implementation of a new Delta parallel robot. Here the entire mechatronic process has been

covered, involving kinematics, control design and optimization methods. The 3D printer is also used to make parts for the final effector to speed up the construction of the robot.

3. DESCRIPTION OF THE CONTROL AND ACTUATION SYSTEM

Figure 1 shows the experimental model of the Delta robot with 3 degrees of freedom. The movement of the Delta robot is performed using three servomotors (q1, q2, q3) that operate the rotating joints, and a actuator (q4) is used to operate the gripper.
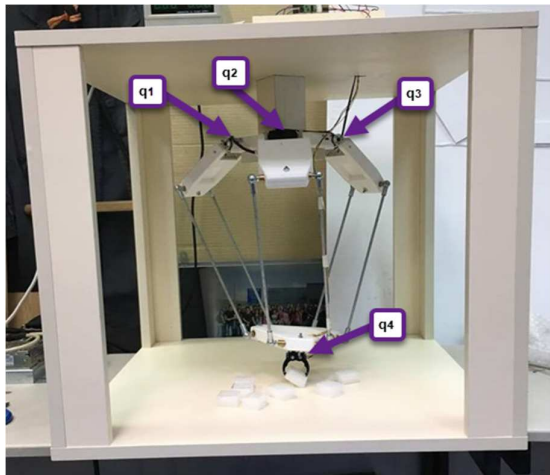

Fig. 1. Delta robotic system

Laboratory tests were performed to evaluate the functionality of the Delta robotic system (Figure 2). For experimental tests, using the gripper (Figure 2, 1), the Delta robot manipulated objects (Figure 2, 2) at different preset points.
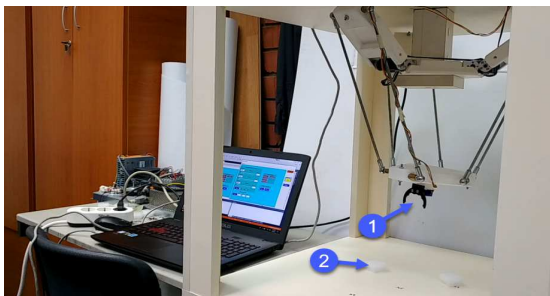

Fig. 2. Experimental tests with the Delta robotic system

The following is presented a block diagram of the control and actuation system of the robotic system.
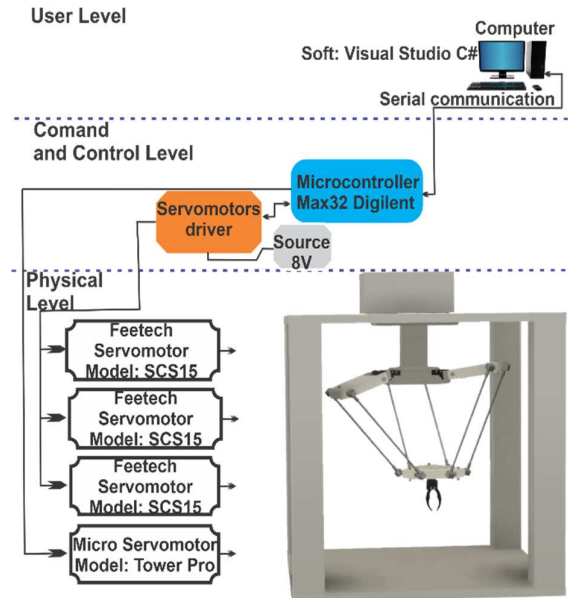

Fig. 3. Block diagram of the control and actuation system

User level - integrates a computer with Visual Studio environment, C# programming language. In this environment, the user interface was developed, through which the robotic system is controlled. Communication between the computer and the microcontroller is done through the serial communication protocol.

The next level, the **Command and Control Level** contains the development board with microcontroller and stepper motor drivers.

• The development board with microcontroller is called chipKIT Max32 from Digilent, this development board uses a PIC32MX795F512L chip. Contains 83 digital input / output pins, 16 analog inputs, 4 UART (hardware serial ports), 2 CAN controllers, an 80 MHz crystal oscillator, 512K Flash memory, 128K RAM, a USB 2 connection, a plug power and a reset button. On this development board is the control program for servomotors. This program is written in the programming environment called MPLAB, in the Ansi C and, Arduino programming language.

Fig. 4. Development board with microcontroller - chipKIT Max32

- The "FeeTech TTLinker" model was chosen for the actuator drivers (Figure 5). This driver is a signal conversion board and uses the serial communication protocol with the following specifications:
  - Weight: 3,5 g;
  - Controller model: 74HC126D;
  - Voltage range: 6V~9V;
  - Recommended voltage: 7,4V (2cell Li-PO battery);
  - Working temperature: -5 °C ~ 60 °C;
  - Communication speed: 8400bps ~ 1M bps.

Figure 6 shows the physical structure of the command and control unit of the robotic system. The main components of this physical command and control structure are: the actuator driver (Figure 6, 1) and the development board with microcontroller (Figure 6, 2).
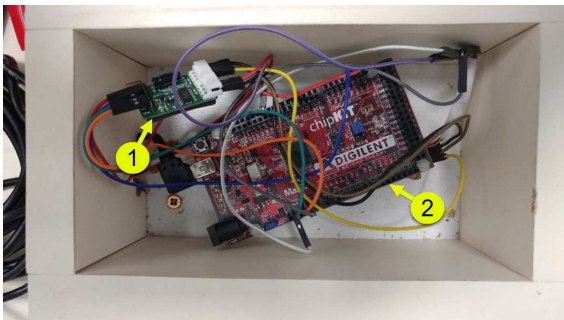

Fig. 5. FeeTech TTLinker driver

Fig. 6. The physical structure of the command and control system

Physical level - contains the following main components:
- Mechanical structure of the Delta serial robot;
- Feetech servomotor, model: SCS15 (Figure 7) with the following specifications:
  - Operating angle: 200 ° (Servomotor mode); Gear type: metal - 275: 1;
  - ID: 254 ID (0 to 253);
  - Communication speed: 38400bps-1Mbps;
  - Operating voltage: 6 - 8,4V;
  - Locking torque (kg.cm): 15@6V, 16.5@7.4V, 17@8.4V;
  - Locking current: 1,5A@7,4V;

Fig. 7. Feetech SCS15 servomotor

- Micro Servo TowerPro SG90 (Figure 8) with the following specifications:
  - Dimension: 22,2x11,8x31 mm;
  - Weight: 9g;
  - Locking torque: 1,8 kgf · cm;
  - Operating speed: 0,1s/60 grade;
  - Operating voltage: 4,8 V (~ 5V);
  - Temperature range: 0ºC - 55ºC.

In the following in Figure 9 a representation of the electrical diagram of the Delta robotic system can be seen. In this representation you can see the connections between the actuators, the actuator drivers, the microcontroller, and the computer.

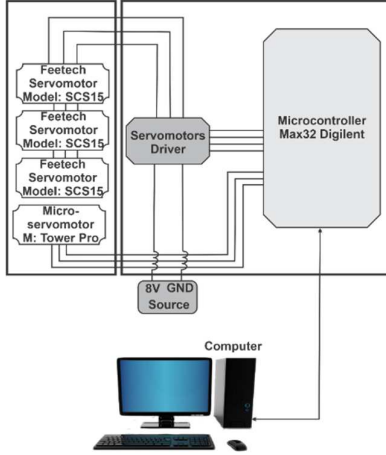**Fig. 8.** TowerPro SG90 microservomotor

Fig. 9. Block diagram of the electrical diagram

3.1 Direct kinematics algorithm used in control

The direct kinematics problem expresses the position of the final effector according to the position of the moving parts. Must be determined X_p, X_p, X_p of the point P belonging to the manipulated object.

$$F_i = (X_i - X_{Ci})^2 + (Y_i - Y_{Ci})^2 + (Z_i - Z_{Ci})^2 - M^2 = 0; \quad (3.1)$$

$X_{Ci} = X'_{ci}\, c\gamma_i - Y'_{ci}\, s\gamma_i$

$Y_{Ci} = X'_{ci}\, s\gamma_i + Y'_{ci}\, c\gamma_i$ - i=1,2,3 Coordinate of C_i in the system OXYZ

$$Z_{Ci} = Z'_{ci} \quad (3.2)$$

$$(X_p + x_i - x_p - X_{Ci})^2 + (Y_p + y_i - y_p - Y_{Ci})^2 + (Z_p + z_i - z_p - Z_{Ci})^2 - M^2 = 0 \quad (3.3)$$

- i= 1,2,3

$$(X_p + x_i - x_p - X_{Ci})^2 + (Y_p + y_i - y_p - Y_{Ci})^2 + (Z_p + z_i - z_p - Z_{Ci})^2$$

$- M^2 = 0$ - i= 1,2,3   (3.4)

$$m_i = x_i - x_p - X_{Ci} \quad n_i = y_i - y_p - Y_{Ci} \quad p_i = z_i - z_p - Z_{Ci} \quad (3.5)$$

$$(X_p + m_{i)})^2 + (Y_p + n_{i)})^2 + (Z_p + p_{i)})^2 = M^2 \quad (3.6)$$

$$(X_p + m_{1)})^2 + (Y_p + n_{1)})^2 + (Z_p + p_{1)})^2 = M^2$$

$$(X_p + m_{2)})^2 + (Y_p + n_{2)})^2 + (Z_p + p_{2)})^2 = M^2 \quad (3.7)$$

$$(X_p + m_{3)})^2 + (Y_p + n_{3)})^2 + (Z_p + p_{3)})^2 = M^2$$

$$2(m_2 - m_1)\, X_p + 2(n_2 - n_1)\, Y_p = -2(p_2 - p_1)\, Z_p + m_1^2 - m_2^2 + n_1^2 - n_s^2 + p_1^2 - p_2^2$$

$$2(m_3 - m_2)\, X_p + 2(n_3 - n_2)\, Y_p = -2(p_3 - p_2)\, Z_p + m_2^2 - m_3^2 + n_2^2 - n_3^2 + p_2^2 - p_3^2 \quad (3.8)$$

$$a_1 X_p + b_1 Y_p = c_1 Z_p + d_1$$
$$a_2 X_p + b_2 Y_p = c_2 Z_p + d_2$$
$$X_p = D_1 Z_p + D_2$$
$$Y_p = D_3 Z_p + D_4 \quad (3.9)$$

Where:

$D = a_1 b_1 - a_2 b_1; \quad D_1 = (b_2 c_1 - b_1 c_2)/D,$

$D_2 = (b_2 d_1 - b_1 d_2)/D; \quad D_3 = (a_1 c_2 - a_2 c_2)/D; \quad (3.10)$

$D_4 = (a_1 d_2 - a_2 d_1)/D.$

$$aZ_p^2 + 2bZ_p + C = 0$$
$$a = D_1^2 + D_3^2 + 1;$$
$$b = D_1(D_2 + m_3) + D_3(D_4 + n_3) + p_3;$$
$$c = (D_2 + m_3)^2 + (D_4 + n_3)^2 + p_3^2 - M^2; \quad (3.11)$$

4. THE USER INTERFACE

For a correct and efficient implementation of the C# application, the diagram of the use cases and the diagrams of activities in the analysis stage are made. The use case diagram [9], shown in Figure 10, comprises two actors, five use cases and relationships of association and dependence [10]. Among the actors, one represents the user of the C# application, and the other is the microcontroller.

For a user interaction with the robotic system, a user interface has been developed that contains well-defined virtual buttons, as can be seen in Figure 11. This user interface contains the following controls:
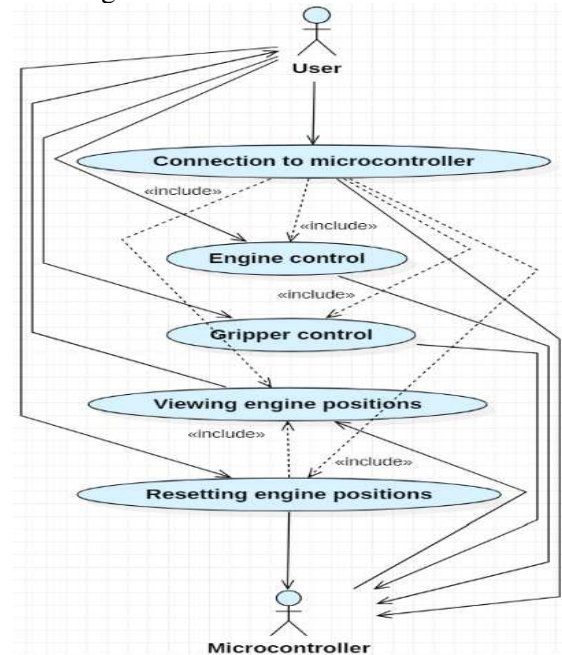

Fig. 10. Use case diagram

- **Home** – when pressing this button, the initialization of the servomotors positions is performed, they will travel to the zero position. Due to the absolute encoder with which the servomotors are equipped, there is no need to attach the proximity sensors to each stroke of the actuators.
- Individual motors control – testing of servomotors individually:
  - **Speed** – setting the speed for each servomotor;
  - **Steps** – setting the number of steps that the servo motors will perform it;
  - **M1**, **M2**, **M3** – choosing the servomotor to be operated;
  - **Start** – pressing this button will start the servomotor that has been selected via M1, M2 and M3.
- **Motors position** – In this field all three servomotors simultaneously are tested. After completing the step control fields for all three servomotors (M1, M2, M3), the "Start" button will be pressed, and from this moment the servomotors will start performing all the preset steps at a preset speed.
- Applications – field with predefined positions:
- when the "Position1, Position2, Position3, Position4, Position5" buttons are pressed, the robot will start on the predetermined paths.
- **Gripper control** – gripper control:
- **Open** – when pressing this button the gripper will be open;

Fig. 11. Control system – User interface

- **Close** – when pressing this button the gripper will be closed;
- **PortConn (On/Off)** - displays the status of the serial port connection (connect / disconnect);
- **Exit** – button to close the user interface.

4.1 Performing steps to control the Delta robotic system via the user interface

When the user interface is opened (Figure 12) by a user, an automatic connection is created between the computer and the microcontroller via a serial port, and when creating this connection, the button in the "PortConn" field displays the status "On" on a yellow background. Once this connection has been created, the user needs to press the "Home" button, and from this moment the robot's servomotors will travel to the zero position. From this position to manipulate an object to move it from side to side it is necessary to create a trajectory of points as follows:

- From the user interface in the field "Individuals motors control" each individual servomotor will be controlled in order to be able to catch the object with the help of the gripper and to create a trajectory of points. Opening and closing the gripper is done from the "Gripper control" field on the user interface. To display the actuator positions in the "Motors position" field on the user interface, the "Start" button will be press. From this moment, at the control of each individual servomotor, it will be possible to see the position of that servomotor, a position that will be memorized together with the state of the "Open, Close" gripper for creating the trajectories of the Delta robot. Once the trajectories have been created, the robot will be able to move to five predefined positions for manipulating objects using the buttons in the "Applications" field.

5. CONCLUSION

The paper presents the control and actuation of a parallel Delta robot. A detailed presentation of the user interface is also made here, which is related to the control program implemented for this type of robot. For the experimental testing
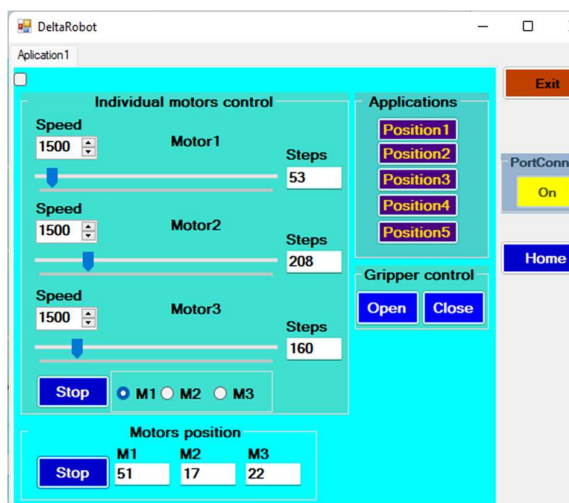
of the robotic system, manipulations of some objects were made in several predetermined points.

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CONTROLUL SI ACȚIONAREA UNUI ROBOT PARALEL CU TREI GRADE DE LIBERTATE

Rezumat: Această lucrare prezintă sistemul de control și acționare al unui robot paralel cu trei grade de libertate. Pentru a controla acest sistem robotic paralel s-a dezvoltat o interfață utilizator prin intermediul căreia utilizatorul poate interacționa cu robotul. Prin intermediul acestei interfețe se pot controla individual servomotoarele robotului prin intermediul unor cursoare. În timpul controlului se pot vedea pozițiile actuale ale celor trei servomotoare pe interfața utilizator deoarece aceste servomotoare sunt echipate cu encodere absolute. După ce s-a făcut o traiectorie de puncte pentru manipularea obiectelor prin intermediul griperului, aceste puncte au fost memorate, iar prin intermediul a cinci butoane de pe interfața utilizator robotul paralel poate manipula obiectele ducându-le în cinci puncte prestabilite.

Florin COVACIU, PhD. Eng., Associate professor, Technical University of Cluj-Napoca, Faculty of Industrial Engineering, Robotics and Production Management, Department of Design Engineering and Robotics, Florin.Covaciu@muri.utcluj.ro, Phone: 0755566491, Bulevardul Muncii street, no. 103-105, Cluj-Napoca, ROMANIA.

Laura-Nicoleta COVACIU, Ph.D. Student, Technical University of Cluj-Napoca, Faculty of Industrial Engineering, Robotics and Production Management, Department of Management and Economic Engineering, laura.covaciu@gmail.com, Phone: 0724564015, Bulevardul Muncii street, no. 103-105, Cluj-Napoca, ROMANIA.