International Journal of Innovative Research and Scientific Studies, 8(4) 2025, pages: 1721-1737

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Advanced working system for coating ceramic workpieces with industrial robots

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Abstract

This research aims to use industrial robots to control the picking of ceramic cups or bowls, dip them in a glaze, and place them on a conveyor belt accurately while being able to control the speed at all times. By using industrial robots to assist in the ceramics industry, it will result in increased speed, reduced working time, and can also decrease the number of workers. Normally, dipping workpieces in an industrial factory requires manual labor to handle approximately 1000 pieces per day. Workers are prone to making mistakes while working and can experience fatigue. Therefore, robots or new technologies need to assist in industrial production. Thus, the purpose of this study is to offer product dipping. Always maintain a high standard of plating, and then deploy industrial robots. Test piece housings on a vacuum are detected by a six-axis module on an industrial robotics station. After that, the module places a test piece insert on the test piece housing after removing it from the slide. In general, the speed and location of glazing ceramics are compared to both manually and mechanically operated methods. At the end of the robot arm is a closed-loop control using a pneumatic servo valve to check the position and speed of the cup. For the system is using the PID controller with $K_p = 0.695$, $K_i = 1.80$, $K_d = 1.65$ and the air pressure is compare with 4, 5 and 6 bar. Overall, the testing of workpiece handling control using a closed-loop servo pneumatic system will operate more accurately than an open-loop system and presents a novel approach to control system design that addresses the pneumatic servo system as a third-order time lag system. The control system with a PID controller at a pressure of 6 bar will operate the fastest and most precisely. The experiment demonstrates the effectiveness of the suggested approach. This eliminates the need for trial and error in determining that all of the proportional gain is one of the control parameters. A pneumatic servo's performance can be enhanced by achieving a greater proportional gain.

Keywords: Ceramic, Clay and Glazes, Materials, Industrial Robotics.

DOI: 10.53894/ijirss.v8i4.8217
Funding: This work is supported by the Government of Thailand (Grant number: 2559A14402001).
History: Received: 30 April 2025 / **Revised:** 5 June 2025 / **Accepted:** 9 June 2025 / **Published:** 1 July 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Acknowledgments: This research was supported by Industrial Product Design, Phranakhon Rajabhat University and Industrial Management Engineering, Suan Sunandha Rajabhat University for their assistance in granting access to the facilities necessary for this research to be completed successfully.
Publisher: Innovative Research Publishing

1. Introduction

The ceramic surface can be developed in a variety of ways, some low-tech, some high-tech, and some no-tech. The wonderful thing about glazing development is that you may take your own approach at any level that seems most comfortable for you. Many famous potters completely detest dealing with calculations in any manner, and they only use empirical methods to make their glazes and colors [1]. They typically build their palette and surface variety within somewhat constrained limitations and become highly intimate with a small handful of favorite materials. This method of working is quite acceptable. Chemical computation procedures have only been around for a little more than a thousand years, but it has been used for at least 5,000 years. The mix of chemistry, mathematics, and analytical techniques frequently inhibits people. There are three different sorts of temperatures that are used for glazing. The temperatures used for 1) low temperature glaze are approximately 800 - 1100 degrees Celsius, 2) medium temperature glaze is approximately 1150 - 1200 degrees Celsius, and 3) high temperature glaze is approximately 1230 to 1300 degrees Celsius [2-4]. Therefore, ceramic items should be cleaned before being coated with glaze. Dust will accumulate on the product's surface, especially if it is left out for an extended period of time. Any glazing with ceramic materials at all can result in the coating coming off the product's surface. Numerous facets of human life have made use of this module. Among these machines' specific benefits are: a) movements that are simple to program and regulate b) excellent precision c) speed across the whole working range d) simplicity of the control system e) a structure that is intrinsically rigid f) broad coverage g) a high payload capacity and h) a straightforward structure with strong dependability.

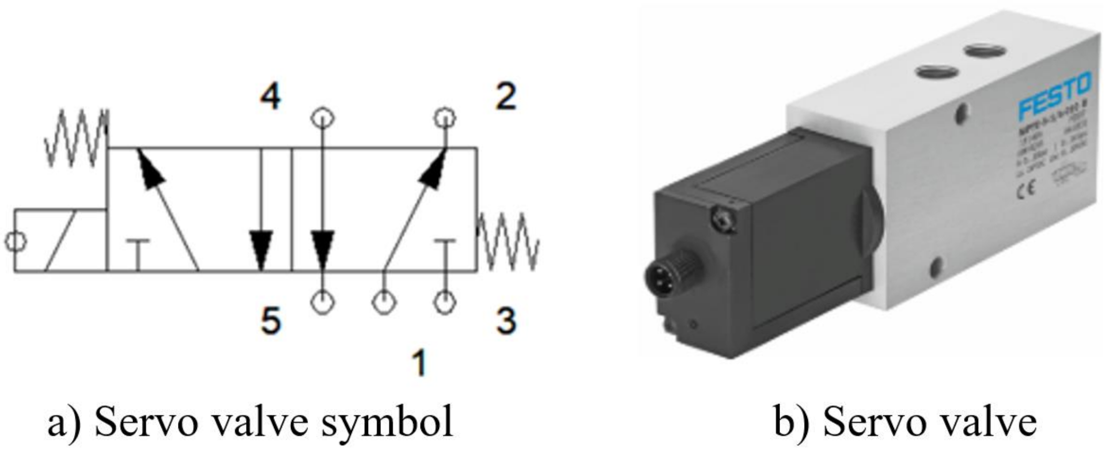


Figure 1.
Pneumatic servo valve.

Industrial robots produce results that are often of very high quality, but they are obtained empirically rather than through scientific theory or expertise. A second diffuse sensor detects the work item after it has been moved to the station's pneumatic separator. This results in carefully regulated activities that provide strict control over the equipment or process.

1.1. PLC

Programmable logic controllers (PLCs) are typically communicated with via Human-Machine Interfaces (HMIs). Compared to previous automation systems, the PLC offered a number of benefits. In addition to being more dependable, smaller, and requiring less maintenance than relay systems, compared to office-use devices, it was designed to endure the industrial environment better. It was simple to expand by adding more I/O modules [5]. A PLC may be adjusted by loading new or modified code, whereas relay systems require laborious and occasionally complex hardware upgrades. This made it simpler to change the design of the production process. Because it used a straightforward programming language focused on logic and switching operations, it was simpler to operate than computers that used general-purpose programming languages.

Ladder logic, which closely mirrored a schematic diagram of relay logic, was used to program early PLCs. It also made it possible to watch how it operated.

1.2. Grippers

Often referred to as hand grippers, these devices are mostly used to test and strengthen the hands; this particular type of grip strength has been dubbed the crushing grip, which denotes that the four fingers, not the thumb, are the primary movers. The physical link that connects a robotic arm to a workpiece is called a robot gripper. Among the advantages is material management.

Therefore, selecting the appropriate gripper type for your application is crucial.

1.3. Spur Gear

The most prevalent kind of gears is spur gears. They are positioned on parallel shafts and have straight teeth. A very large gear reduction is achieved by using many spur gears. Spur gears can be constructed from plastics like nylon or polycarbonate or metals like brass and steel. Plastic gears are quieter, but they sacrifice strength and load capacity. The optimum uses for spur gears are in applications like ball mills and crushing equipment that need to reduce speed and increase torque.

1.4. Conveyor Belt

Conveyor belts that circle them are used to move materials. The belt and its contents move forward when one or both pulleys are powered. The unpowered pulley is referred to as the idler pulley, and the powered pulley is known as the drive pulley. The two main industrial classifications of belt conveyors are bulk material handling; it includes general material handling as well as the transportation of enormous volumes of resources and agricultural products such as coal, ore, grain, salt, sand, overburden, and more, which includes moving boxes inside a factory. Conveyor belts are used in our project to move objects from one location to the arm position.

1.5. DC Motor

Four D.C. motors were utilized in our project to move the gripper, the arm up and down, the arm rotation, and the conveyor belt. The following are its specifications: motors with a metal gearbox and 10 rpm and 12 VDC; 6 mm is the shaft diameter. Length of shaft: 15 mm; Torque at stall: 49 kg cm; Current without load: 800 mA (max); Maximum stall current: 9.5 A (max). A workpiece insert is taken from the slide by the pick and place module, which then positions it on the workpiece housing. This work aims to explain how to attain optimum control performance when comparing speed and position control that is done manually and automatically. The conceptual design of robotics kinematics is the main topic of discussion in Section 2. Experimental results via machine and human control are divided in Section 3. Section 4 concludes the paper overall.

2. Characteristics of Ceramic

Like other materials, ceramics are characterized by the kinds of atoms they contain, the kinds of bonds they form, and how they are arranged. The atomic-scale structure is the name given to this. The majority of ceramics consist of two or more components. We refer to this as a compound. For instance, aluminum atoms and oxygen combine to form the chemical alumina (Al_2O_3). Chemical bonds hold atoms in ceramic materials together. In ceramic materials, covalent and ionic connections are the two most common types of chemical bonds [4]. The chemical bond present in metals is known as the metallic bond. Atoms are held together far more securely by covalent and ionic connections than by metallic ones. Because of this, metals are ductile while ceramics are frequently brittle. Due to their wide spectrum of properties, ceramic materials are used in a wide variety of applications. Typically, the majority of ceramics are thermal insulators, electrical insulators, oxidation resistant, and so on. Even though metals and alloys are used in many engineering applications, other engineering materials such as ceramics and polymers still have important roles to play. Ceramics are particularly crucial in numerous applications involving high temperatures. Tools and protective covers for harsh settings are two significant uses for ceramics. Ceramics are a significant component of the materials group. Composites of metallic and nonmetallic materials with ionic or primarily ionic interatomic bonding are known as ceramics. The Greek word keramikos, which means "burnt stuff," is where the name "ceramics" originates. Another example using both clay and feldspar will help to clarify the process of ceramic bowls that add many oxides to the glaze [6, 7]. Assume that the objective is to use the provided meaning formula to calculate the recipe for a lead glaze as given in Table 1. The raw materials, feldspars, are represented in the table by formulas that are exactly the same as the empirical glaze formula previously mentioned. The first column, which equals one, contains the alkali and alkaline earths as shown below.

Table 1.
Glaze formula for ceramics.

Raw material	Molecular weight (%)
$K_2O.Al_2O_3.6SiO_2$	37%
SiO_2	27%
$Al_2O_3.2SiO_2.H_2O$	8%
$ZrSiO_4$	10%
ZnO	2%
$CaCO_3$	16%

The values of the alumina and silica are derived from the values in the first column. The procedure utilized in the preceding example to obtain the formula for a glazed hatch is also used to obtain the formula for feldspar, or any other material for that matter. There are used in Table 2.

Table 2.
Feldspar formula.

Raw Material	Molecular weight (%)
SiO_2	66.20%
Al_2O_3	18.40%
CaO	1.60%
K_2O	10.80%
Na_2O	2.00%

Figure 2.
Mixing machine.

The process of preparing clay, in a pugmill or occasionally a dry mill, when the clay's consistency during mixing is lower than the wet mix, the clay is first prepared using a semi-wet mix. As a result, not a lot of raw materials are used in the production process. Usually, the only materials used as filters are clay and kaolin, or chamotte. Water is supplied to a pugmill or dry mill to change the clay's moisture level [8]. The clay will be crushed by passing it through a roller. The roller breaks off the gravel that has been combined with the clay, but it progressively adjusts its distance so that it can be crushed completely.

Figure 3.
Clay crushing machine.

Figure 4.
A dry pant mill.

The weight formula for the different glazing materials based on the relative amounts of their molecules, management techniques is contained in the weight of clay and water. To create the formula weight, the formula's values are multiplied by the molecular weight of the clay. The totals are then added up as follows:

$$P = K\left(\frac{R}{100}\right)(C - 0.001) \tag{1}$$

Where $P =$ value of glazing (g / cm^2)

$C =$ value of coherence (g / cm^2)

$K =$ constant of deposition

$R =$ taken of the body (gH_2O*10^4 / cm^2)

$0.001 =$ value of water coherence (g / cm^2)

So, if the computation is done in a tabular fashion, with all of the oxides in the formula and their amounts listed across the top, and with the raw materials needed to satisfy the formula arranged, the mathematics involved in this simple calculation will become clear. This type of table is frequently used to track the quantity of different oxides provided by the basic components when preparing glazes.

Table 3.
Comparing the Composition of Four firing temperature and Four Glaze formulas.

Cone No.	Temp.	Composition					
		K_2O	M_gO	C_aO	B_3O_3	Al Glaze formulas$_2O_3$	SiO_2
1	1080ºC 1978ºF	0.06	1.3	0.42	0.6	0.3	2.8
2	1200ºC 2192ºF	0.2	0.1	0.7	0.1	0.46	3.5
3	1230ºC 2246ºF	0.2	0.1	0.7	-	0.4	3.5
4	1410ºC 2570ºF	2.8	1.3	6.6	11.6	8.4	46.5

3. Methodology

The FANUC Robot was designed to have a high speed and a 6 kg payload capacity. FANUC is committed to creating robots that satisfy the demands of many sectors. Material handling robots, tiny assembly robots, robotic packaging solutions, and coating, sealing, and dispensing robots are just a few of the automobile assembly robots in which FANUC specializes. We also offer manufacturing solutions for a variety of industries, such as food & beverage, electronics, medical and pharmaceutical, die-cast, mold, aerospace, and agriculture. One of the most popular robots that manufacturers are selecting for their new applications is the 6-axis robot [5, 9, 10]. The functionality and range of motion of the six-axis robot allow it to mimic the complex motions of the human arm. Apart from the standard industrial six-axis robot that is present in many manufacturing companies, the robot, also known as a collaborative robot, is becoming more and more common. Despite being a six-axis robot as well, the robot differs greatly from the conventional six-axis robot in a number of ways.

Forward Kinematics: This method uses the angles of a robot's joints to determine the location and orientation of its end-effector, such as a gripper, hand, or tool. It's similar to knowing the joint angle input and figuring out the end-effector position output.

Inverse Kinematics: This procedure is reversed. It determines the required joint angles to put the end-effector in the proper position and orientation. It's similar to determining the input as joint angles and knowing the output with end-effector location [11, 12].

Determining the gripper frame's location and orientation when the joint variables are quantitatively determined is the focus of the inverse and forward kinematics problem.

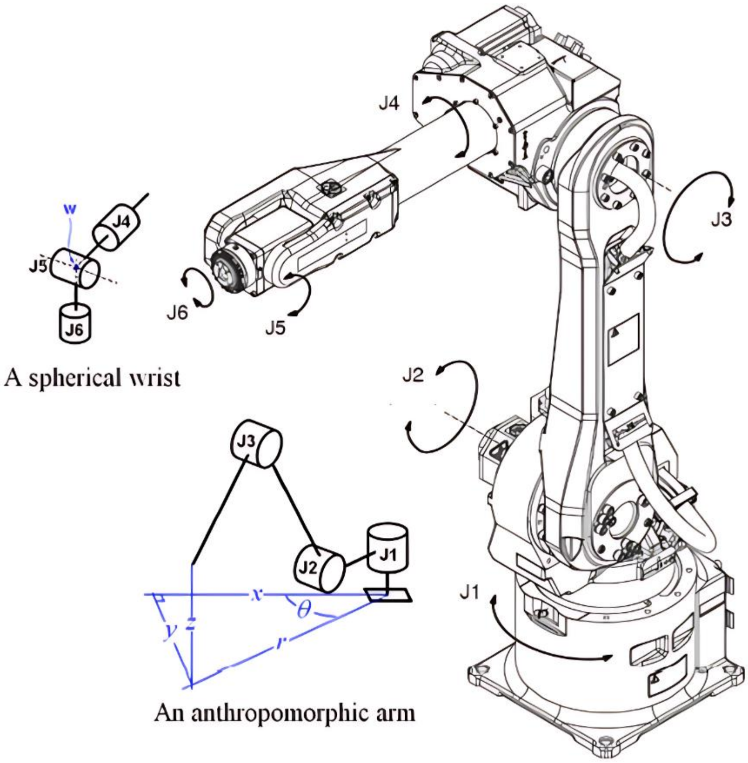


Figure 5.
An industrial robotics FANUC robot.

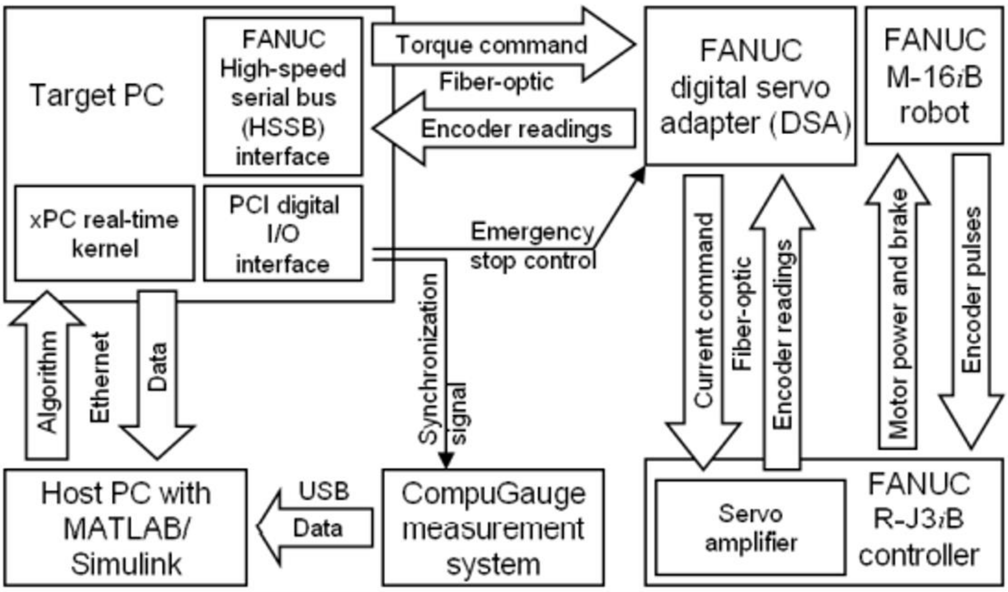


Figure 6.
System of control for a FANUC robot.

3.1. A Link Details

A computer can be used to control the 6-axis robot so that the tool tip can move in any direction. The six links in a FANUC Robot frame assignment are coordinates shown in Figure 7.

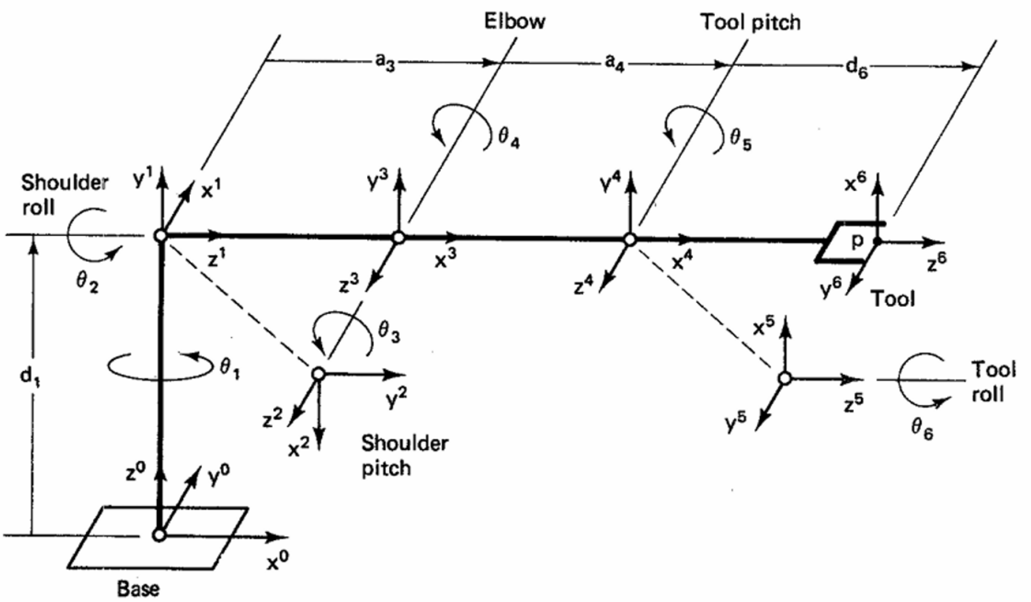


Figure 7.
Connection coordinates for an articulated robot with six axes.

Table 4.
Kinematic characteristics of an articulated robot with six axes.

Axis	$\boldsymbol{\theta}$	$\boldsymbol{d}$	$\boldsymbol{a}$	$\boldsymbol{\alpha}$	$\boldsymbol{Home}$
1	q_1	d_1	0	$\pi/2$	$\pi/2$
2	q_2	0	0	$\pi/2$	$-\pi/2$
3	q_3	0	a_3	0	$\pi/2$
4	q_4	0	a_4	0	0
5	q_5	0	0	$\pi/2$	$\pi/2$
6	q_6	d_6	0	0	0

3.2. Matrix of Transformation

The position and orientation of the mobile tool must be expressed in terms of a coordinate frame connected to the stationary base using coordinate transformations that include both rotations and translations. Start by investigating the 4 x 4 matrix representation of rotations and coordinate transformations:

$$T^{robot} = T_0^1 T_1^2 T_2^3$$

$$= \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_2 & 0 & S_2 & 0 \\ S_2 & 0 & -C_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_3 & S_3 & 0 & a_3C_3 \\ S_3 & C_3 & 0 & a_3S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} C_1C_2 & S_1 & C_1S_2 & 0 \\ S_1C_2 & -C_1 & S_1S_2 & 0 \\ S_2 & 0 & -C_2 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_3 & -S_3 & 0 & a_3C_3 \\ S_3 & C_3 & 0 & a_3S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} C_1C_2C_3 + S_1S_3 & -C_1C_2S_3 + S_1C_3 & C_1S_2 & (C_1C_2C_3 + S_1S_3)a_3 \\ S_1C_2C_3 - C_1S_3 & -S_1C_2S_3 - C_1C_3 & S_1S_2 & (S_1C_2C_3 - C_1S_3)a_3 \\ S_2C_3 & -S_2S_3 & -C_2 & d_1 + S_2C_3a_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

The positions and orientations of the X_3 frame with respect to the base frame X_0 are provided by the transformation $T^{robot}(\text{Home})$. as a preliminary verification of the robot expression. It can be considered the soft home position. This is $q=[\pi/2,-\pi/2,\pi/2,0,\pi/2,0]^T$ yields, as indicated.

$$T^{robot}(Home)=\begin{bmatrix}1&0&0&a_3\\0&0&-1&0\\0&1&0&d_1\\0&0&0&1\end{bmatrix} \tag{3}$$

Figure 7 shows that the link coordinate diagram and the specification of frame X_3 position and orientation with respect to frame X_0 are compatible. The tool's orientation and position in relation to the robot are then ascertained.

$$T^{robot}=T_3^4T_4^5T_5^6$$

$$=\begin{bmatrix}C_4&-S_4&0&a_4C_4\\S_4&C_4&0&a_4S_4\\0&0&1&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}C_5&0&S_5&0\\S_5&0&-C_5&0\\0&1&0&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}C_6&-S_6&0&0\\S_6&C_6&0&0\\0&0&1&d_6\\0&0&0&1\end{bmatrix}$$

$$=\begin{bmatrix}C_{45}&0&S_{45}&a_4C_4\\S_{45}&0&-C_{45}&a_4S_4\\0&1&0&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}C_6&-S_6&0&0\\S_6&C_6&0&0\\0&0&1&d_6\\0&0&0&1\end{bmatrix}$$

$$=\begin{bmatrix}C_{45}C_6&-C_{45}S_6&S_{45}&a_4C_4+S_{45}d_6\\S_{45}C_6&-S_{45}S_6&-C_{45}&a_4S_4-C_{45}d_6\\S_6&C_6&0&0\\0&0&0&1\end{bmatrix} \tag{4}$$

3.3. Control Theory

Using a PID controller, we provide a complete mathematical description of servo pneumatic pick and place for dip glazing, such as pneumatic actuators, position transducers, electronic devices, and high speed, which make up the system. Our research uses a double-acting cylinder as the servo pneumatic system. In industrial processes, PID controllers are currently the most often used. They perform a number of crucial tasks, including feedback, using integral action to remove steady-state offsets and derivative action to forecast future events. Multivariable controllers supply the set point, while PID controllers are utilized at the lowest level in practice. A PID algorithm's behavior can be characterized as

$$u(t)=K_p\left(e(t)+\frac{1}{T_i}\int_0^1 e(t)dt+T_d\frac{de(t)}{dt}\right) \tag{5}$$

where K_p is the proportional action, T_i is the integral time and T_d is the derivative time. The following transfer function is used to parameterize the PID controller.

$$\frac{X(s)}{R(s)}=\frac{C(s)G(s)}{1+C(s)G(s)} \tag{6}$$

The third-order closed loop is provided as

$$G(s) = \frac{5430.58}{S^3 + 179.65S^2 + 8069.07S} \tag{7}$$

Transfer function of Eq.(6) using Eq.(7) as follows:

$$\frac{K_p(1+T_{ds}+\frac{1}{T_{is}})\frac{K}{s(1+T_{p1s})(1+T_{p2s})}}{1+K_p(1+T_{ds}+\frac{1}{T_{is}})\frac{K}{s(1+T_{p1s})(1+T_{p2s})}} \tag{8}$$

The PID controller was created using the typical PID controller design process, which includes the control and plant components as shown in Figure 8. Results obtained with a PID controller are provided as $K_p = 0.695$, $K_i = 1.80$ and $K_d = 1.65$

4. Experiment and Results

The product surface is adorned with a variety of designs created by scribbling, parallel grooving, and carving. Moreover, the product must be completed before being burned. Therefore, as illustrated in Figure 8, shown a dish for painting preparation and Figure 9 shown Flowchart of programming for robot movement.

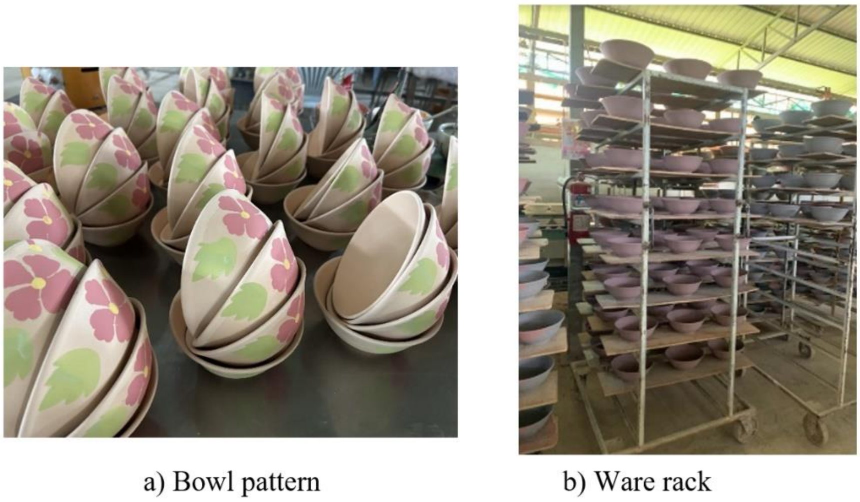


Figure 8.
A dish for painting preparation.

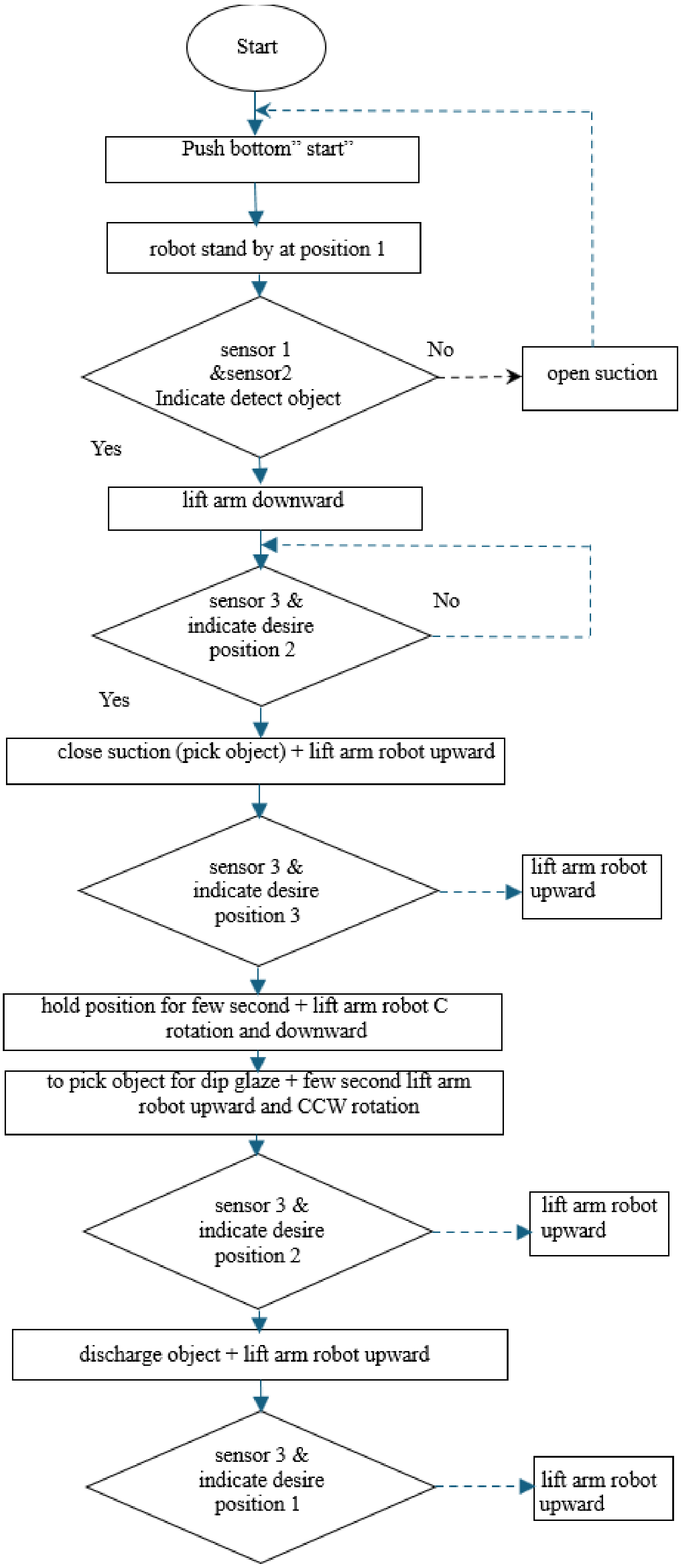


Figure 9.
Flowchart of programming for robot movement.

From Figures 8 and 9, controlling the robot and the servo pneumatic are the most important. Using position and speed observers, experiments were carried out to implement and evaluate the suggested controller's efficacy and accuracy. Flexible feeders present components to a machine vision system for robotic pick and place operations using a variety of methods, including robotic or pneumatic systems. These feeders are useful in industrial settings with a variety of product lines because they can be adjusted to accommodate components of various sizes and shapes. The capacity of flexible feeders to handle parts with complex geometries and irregularly shaped objects is one of its main features. Flexible feeders may have additional restrictions in addition to the size restrictions. Particularly when working with complex pieces that need exact alignment, they may be slower than other part choosing methods. Furthermore, the initial calibration and setup of flexible feeders can take a lot of time and may call for knowledgeable staff that are proficient in pneumatics and robotics.

4.1. Industrial Robot Experiment Results

The bowl may be held in the gripper position by the robotic manipulator. After that, the bowl will be placed on the belt conveyor. A sensor detects when the bowl is removed from the conveyor and alerts the robot.

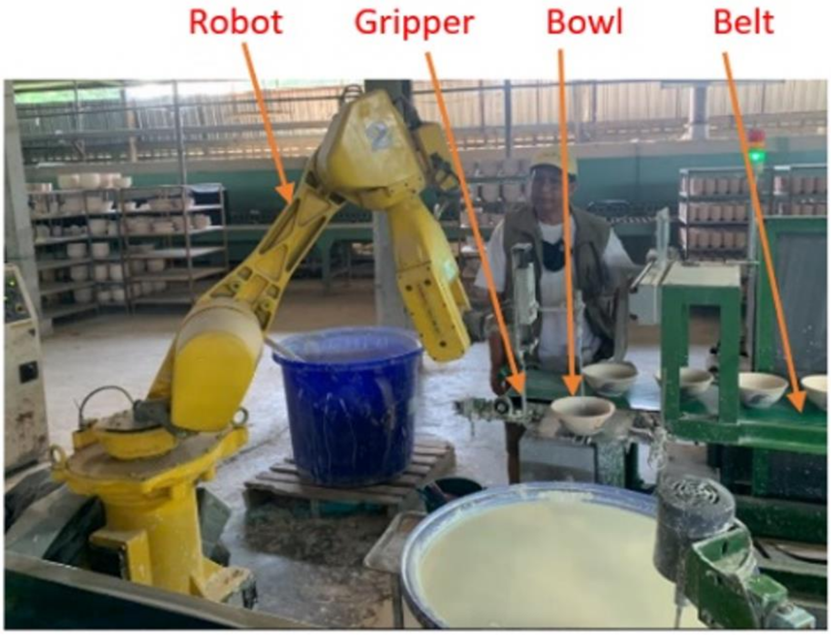


Figure 10.
Ceramic bowl glazing that is automated (step 1).

Next step, the robots will then move in relation to one another along all six axes, lowering the bowl and dipping it in the glaze blunger by less than ten seconds.

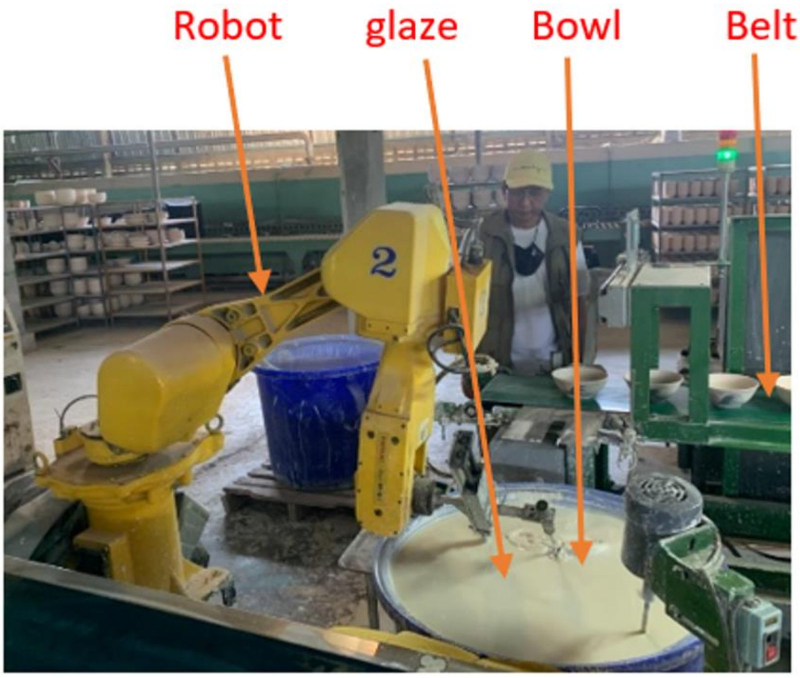


Figure 11.
Ceramic bowl glazing that is automated (step 2).

Finally, after a bowl of glazed has been fastened by the robot. The bowl will be placed on the output of the conveyor belt.

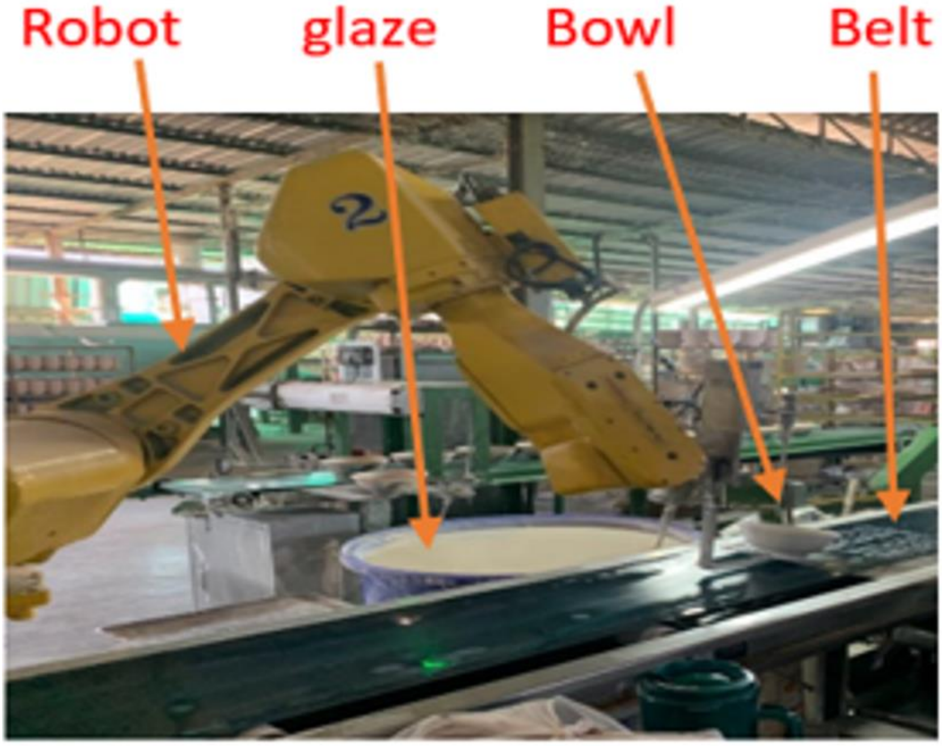


Figure 12.
Ceramic bowl glazing that is automated (step 3).

4.2. Simulation and Experiment Results

An experimental system was used to validate a Simulink model for the servo-pneumatic. A load flow, pressure, velocity, force, and other dynamics necessary for a pneumatic system were all incorporated into the dynamic model. Tests of the observer's sensitivity to variations in the model parameters were included in the simulation. The input, output, velocity, pressure, and flow rate were the parameters that were changed in the simulations.

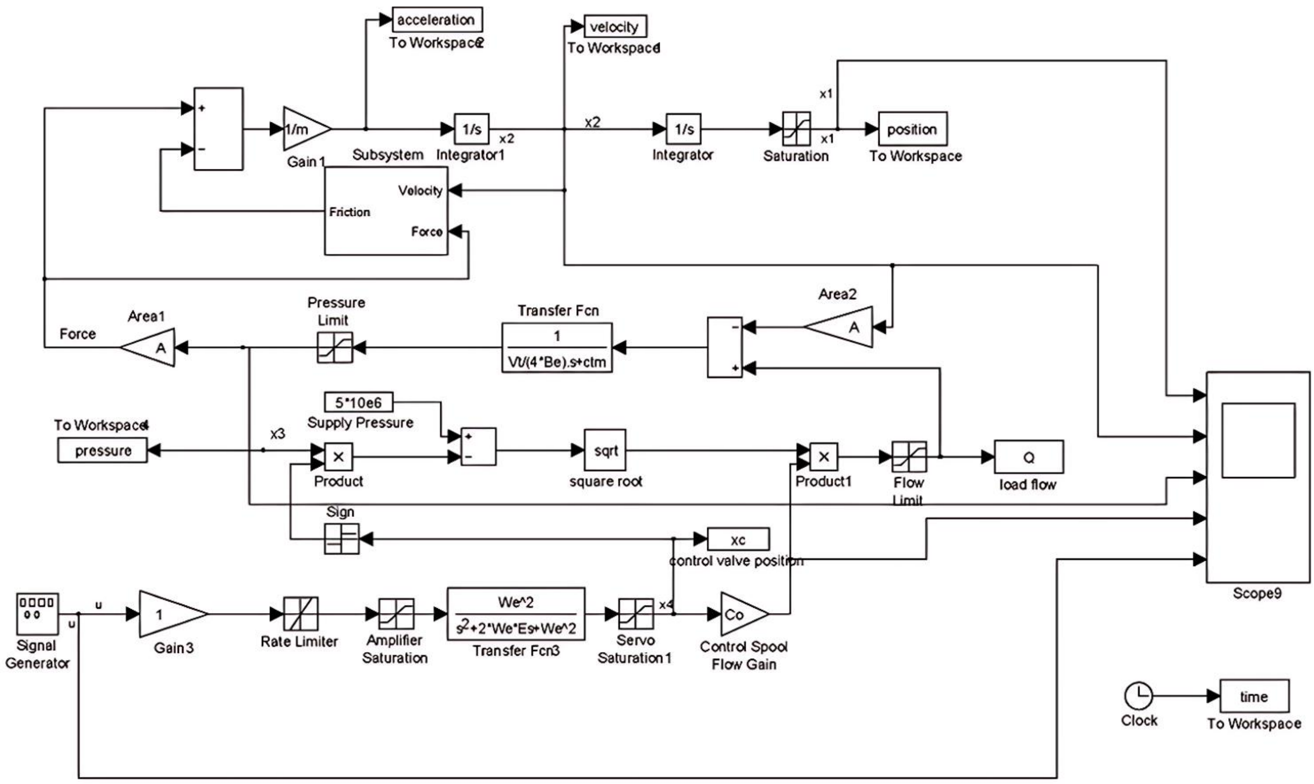


Figure 13.
Simulation model of the pneumatic servo valve.

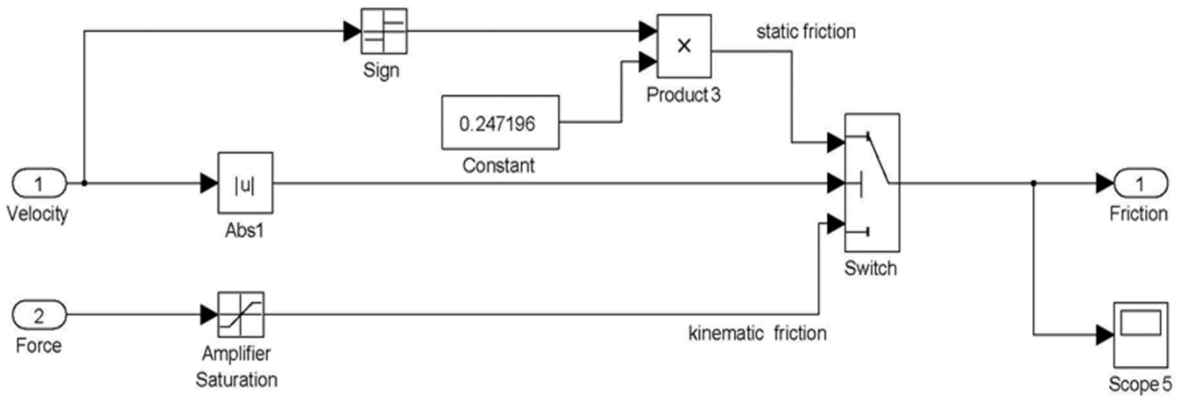


Figure 14.
A force, velocity, and friction model modified.

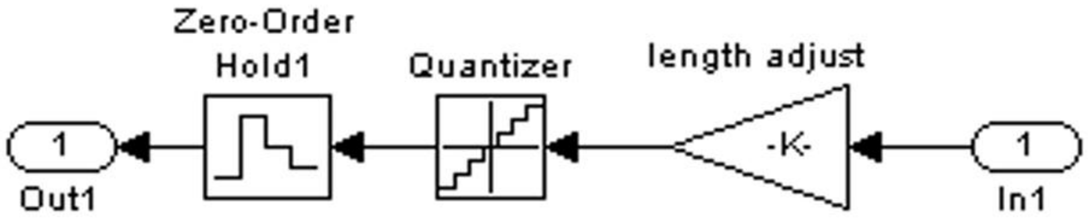


Figure 15.
A linear potentiometer block diagram.

Both the static and dynamic tests are run in simulation and compared with the experimental data to confirm and validate the model. The Simulink technique in the MATLAB software is used to model the controller for both the validation of the model and the PID controller tests. The following displays the experimental findings for the PID controller, which are based on position and velocity control at an operating supply pressure of 4-6 bar. In addition to being used in a variety of industrial settings, pneumatic servo systems have been thoroughly researched for ways to improve controllability and compensate for their nonlinearity through robust control. The transfer function in a third-order time lag system has been used in the control system design of a pneumatic servo system. This is based on the notion that while servo valve dynamics are fast enough compared to cylinder dynamics, they are not important. Nonetheless, a servo valve's characteristics have a significant impact on the pneumatic servo's dynamic characteristics and must be considered while designing the control system.

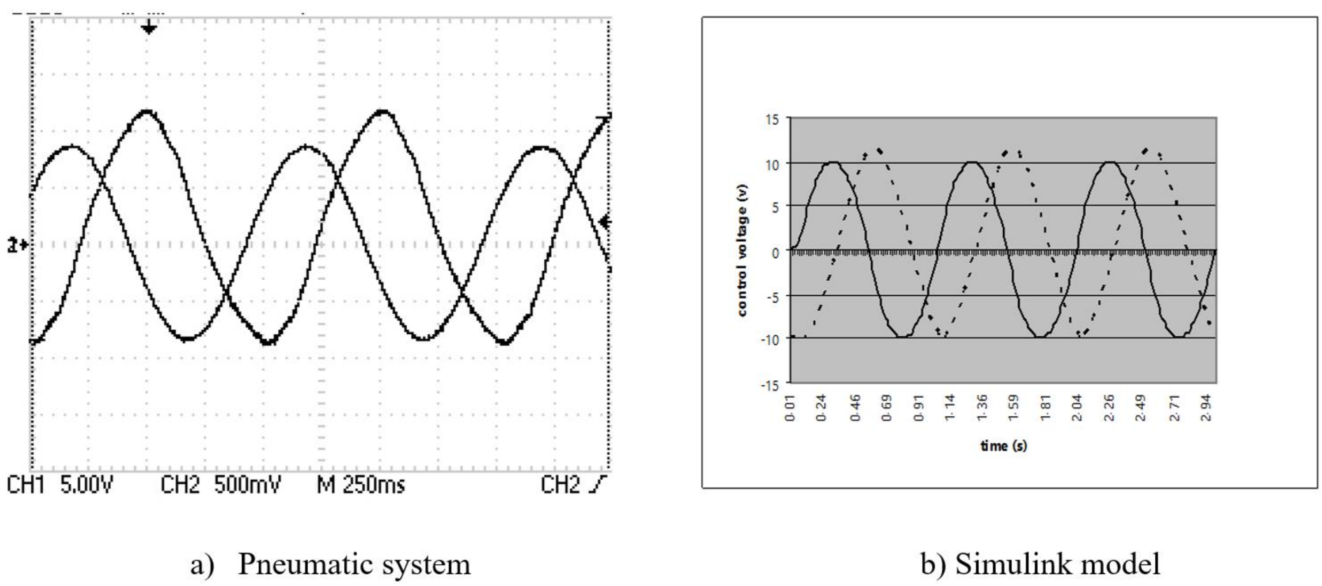
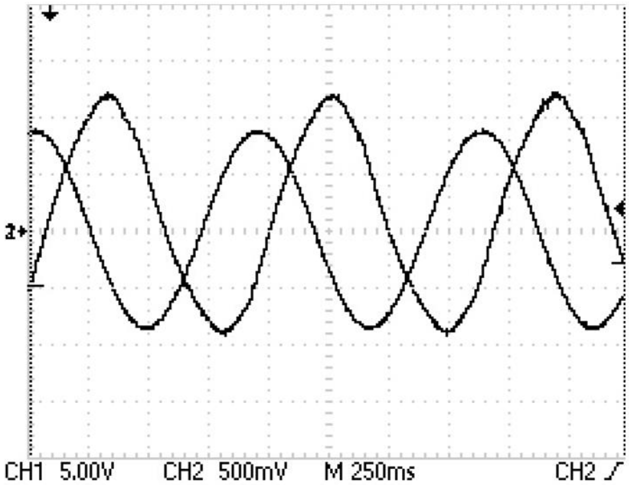
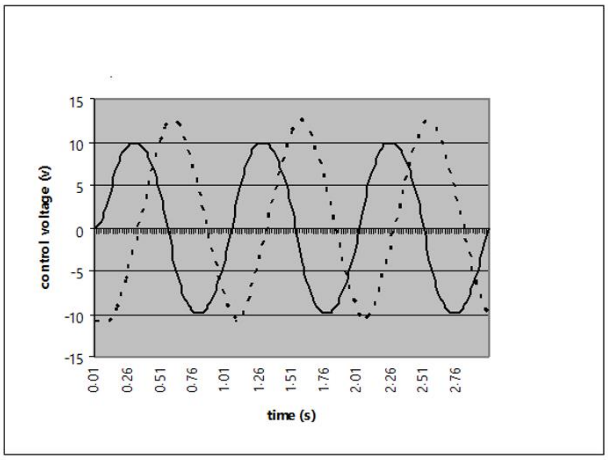


Figure 16.
Input and output system for 4 bar.

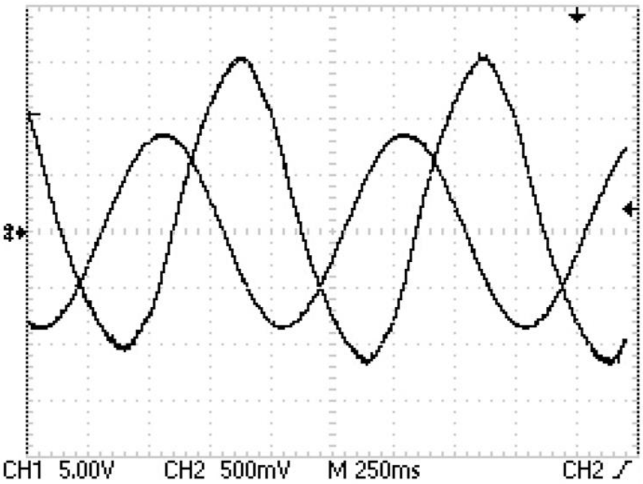


a) Pneumatic system

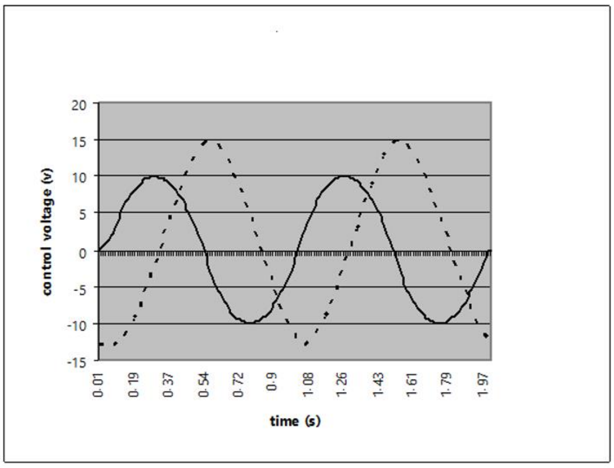


b) Simulink model

Figure 17.
Input and output system for 5 bar.

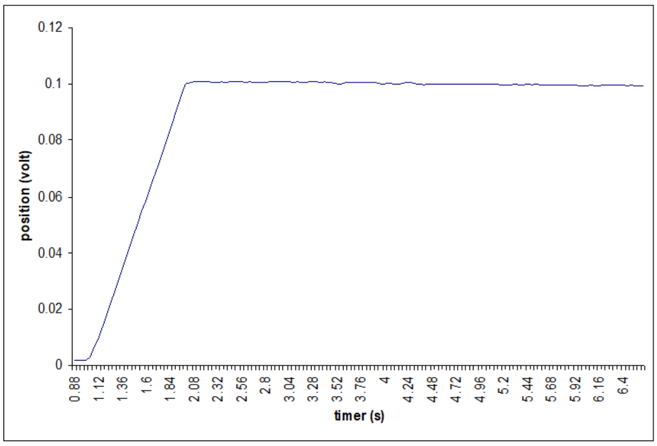


a) Pneumatic system

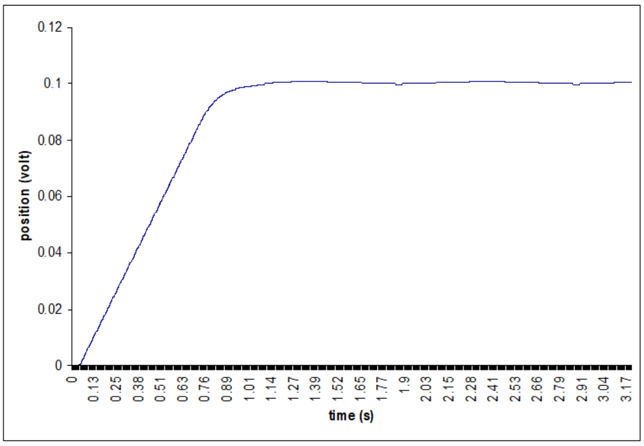


b) Simulink model

Figure 18.
Input and output system for 6 bar.

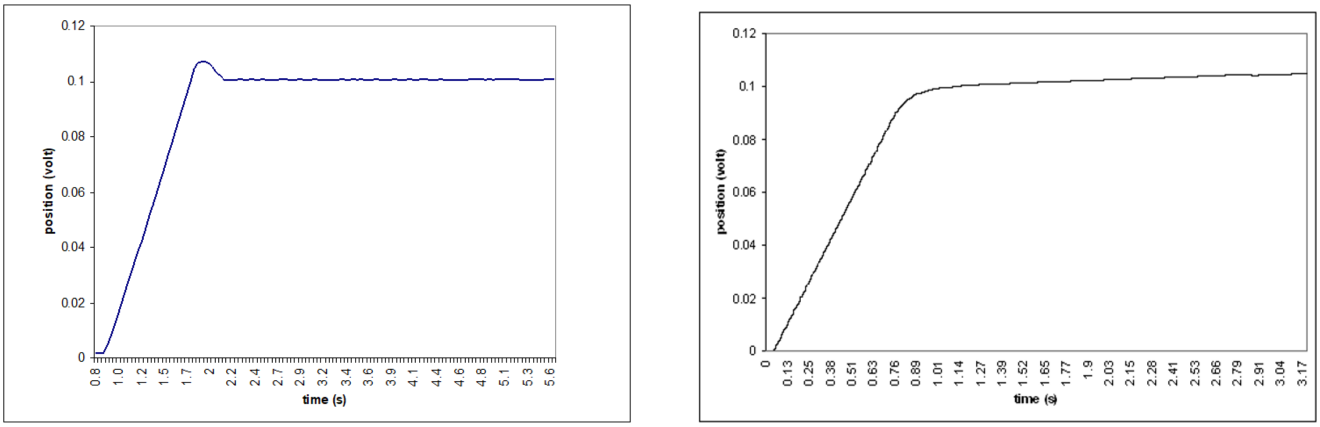


a) Pneumatic system



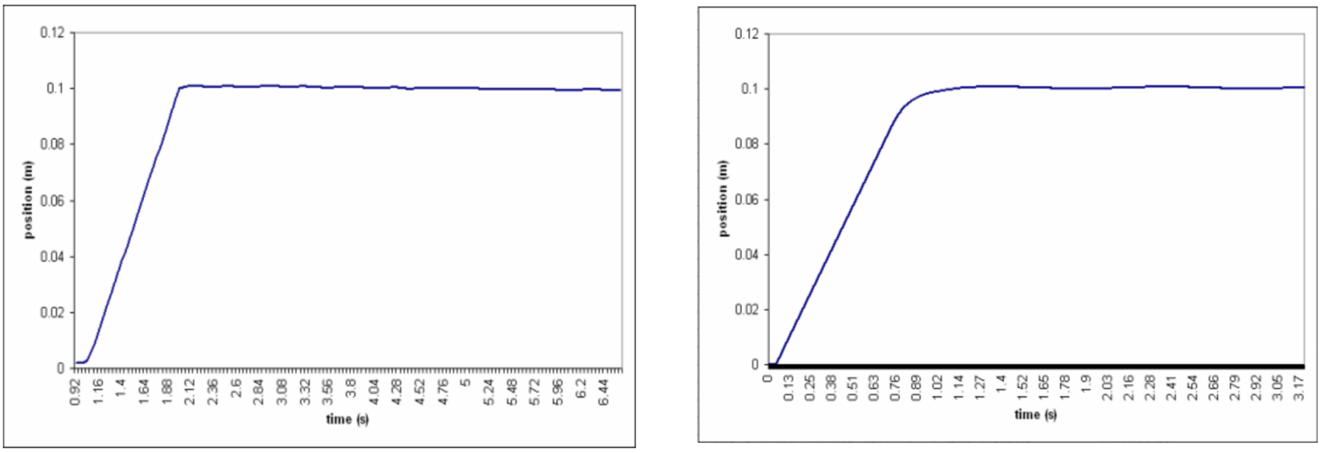
b) Simulink model

Figure 19.
Position responses of a PI control.



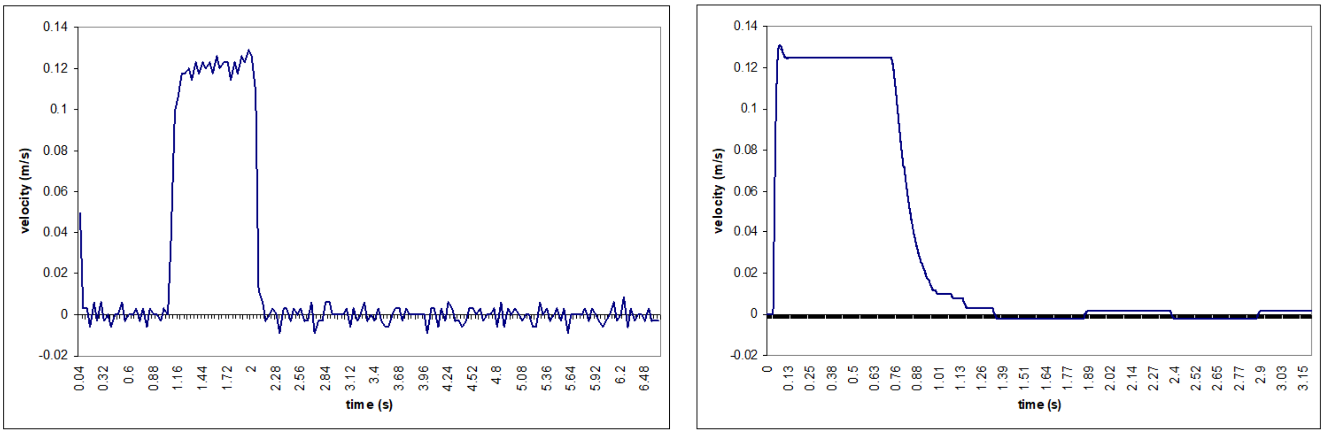
a) Pneumatic system b) Simulink model

Figure 20.
Position responses of a PD control.



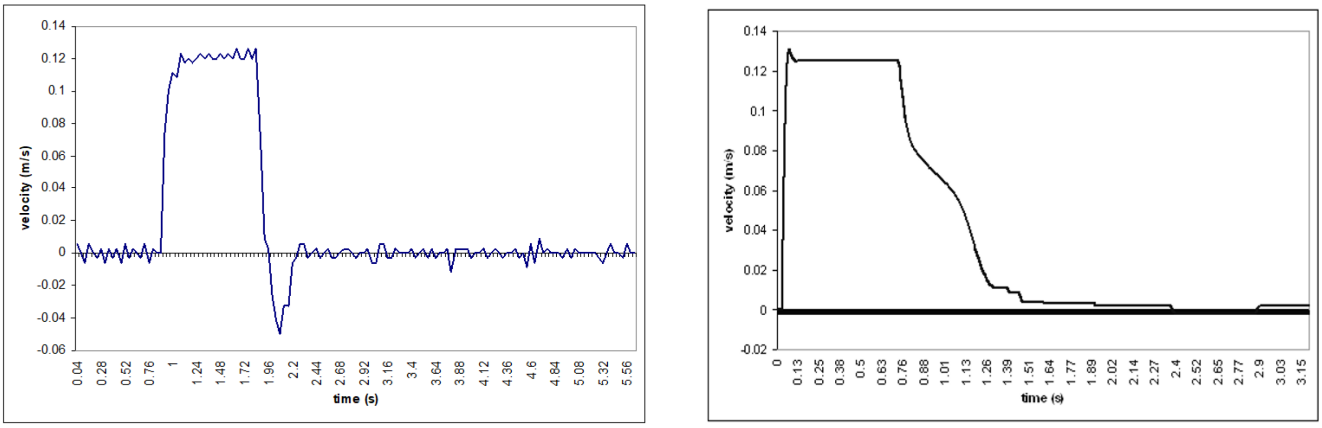
a) Pneumatic system b) Simulink model

Figure 21.
Position responses of a PID control.



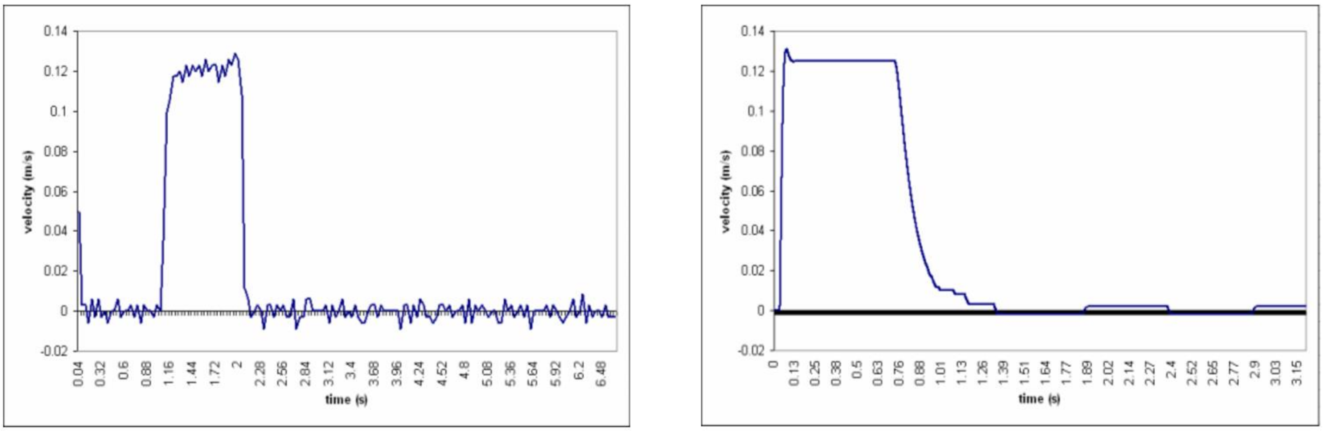
a) Pneumatic system b) Simulink model

Figure 22.
Velocity responses of a PI control.



a) Pneumatic system b) Simulink model

Figure 23.
Velocity responses of a PD control.



a) Pneumatic system b) Simulink model

Figure 24.
Velocity responses of a PID control.

5. Conclusion

For pneumatic servo, the system has demonstrated deviation, simulation, and application of the nonlinear control law. For high-speed control, the suggested controller offers the performance of the PID controller. This paper introduces PID controller theory as a control strategy to achieve this goal, and experimental testing is used to validate the controllers created with this approach. These tests demonstrate that control theory offers a potent control technique that significantly outperforms PID control in terms of high speed and transient response for pneumatic systems, which have nonlinear properties. The outcome displays the proportional-derivative controller with $K_p = 0.695$, $K_i = 1.80$ and $K_d = 1.65$ as well as the simulation and experiment time constants. Overall, the reference velocity and position are 45 mm. The comparison of the findings between the hardware system and Simulink for the best PID controller shows that the simulation study has improved. As a result, the model's response predicts the PID controller's control performance well.

References

[1] H. J. Ju, Q. Zhao, and X. Sun, "Microwave oven design using HFSS simulation software," *Material Review A*, vol. 11, pp. 237-239, 2007. https://doi.org/10.4236/ojpm.2013.39072

[2] M. B. Tian, *Substrates for high density package engineering*. Beijing: Tsinghua University Press, 2003.

[3] Y. Rao, C. P. Wong, J. Qu, and T. Marins, "A precise numerical prediction of effective dielectric constant for polymer-ceramic based on effective medium theory," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 23, pp. 680-683, 2003. https://doi.org/10.1145/3382025.3414945

[4] F. H. Norton, *Elements of ceramics*. Masssachasetts: Addison-Wesley Publishing Company, 1957.

[5] J. C. John, *Introduction to robotics: Mechanics and control*. United States: Prentice Hall, 2005.

[6] X. Ding, "Design and implementation of an automatic ceramic powder weighing system," *Foshan Ceramics*, vol. 12, no. 12, pp. 25-28, 2002. https://doi.org/10.14445/22315381/IJETT-V70I2P224

[7] Y. Huang, J. Luo, and B. Xia, "Application of cleaner production as an important sustainable strategy in the ceramic tile plant–a case study in Guangzhou, China," *Journal of Cleaner Production*, vol. 43, pp. 113-121, 2013. https://doi.org/10.1016/j.jclepro.2012.12.013

[8] W. L. Wang, F. Zhu, and W. Q. Zhu, "A summary of automation technology development for ceramic tile production line," *China Ceramics,* vol. 42, no. 1, pp. 4-7, 2006. https://doi.org/10.4236/jgis.2019.116043
[9] X. Suhua, "Design of six-degree-of-freedom manipulator system," *Journal of Physics: Conference Series*, vol. 1748, no. 6, p. 062046, 2021. https://doi.org/10.1088/1742-6596/1748/6/062046
[10] M. Bechthold, "Integrated environmental design and robotic fabrication workflow for ceramic shading systems," in *Proceedings of the 28th International Symposium on Automation and Robotics in Construction (ISARC2011), Seoul*, 2011, doi: https://doi.org/10.22260/ISARC2011/0010.
[11] I.-W. Park, B.-J. Lee, S.-H. Cho, Y.-D. Hong, and J.-H. Kim, "Laser-based kinematic calibration of robot manipulator using differential kinematics," *IEEE/ASME Transactions on Mechatronics,* vol. 17, no. 6, pp. 1059-1067, 2011. https://doi.org/10.1109/TMECH.2011.2158234
[12] T. Chen, "Review on kinematics calibration technology of serial robots," *International Journal of Precision Engineering and Manufacturing*, vol. 8, pp. 1759-1774, 2014. https://doi.org/10.57062/ijpem-st