Advanced Sciences and Technology Journal

ASTJ vol. 1 (2024) 1004
10.21608/astj.2024.298658.1004
https://astj.journals.ekb.eg/

Design Smart Wall Painting Mobile Robot with X-Y Table

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ARTICLE INFO

Article history:
Received 22 June 2024
Revised 8 July 2024
Accepted 23 October 2024
Available online 24 October 2024

Handling Editor:
Prof. Mohamed Talaat Moustafa

Keywords:
Painting Robot,
X-Y Table,
Wheel design,
Control Design,
Mechanical Design

ABSTRACT

In this paper, a new painting robot using a roller for indoor wall painting has been implemented. The main criteria for the new design are simplicity, rigidity, stability, user-friendly interface, lightweight, speed, and cost. This robot will paint walls by using a roller fed with paint from a pump. The roller scans the wall vertically while the robot mobile base will move autonomously inside the room walls to finish painting. The robot consists of a differential drive base over which is attached a linear cascaded lift mechanism that lifts a painting x-y stage to fixed heights of the wall. The x-y stage then scans a fixed area of the wall with its tip fitted with a standard pump-fed roller. The design is made such that the heavier lift mechanism is subject to less motion and then less wear compared to the light x-y stage. The robot is implemented with simple control and user interface. Experiments showed that the system has good performance with a weight of 20 kg and a painting rate of 5 m^2/hr.

1. Introduction:

Building a robot that can autonomously paint walls with little to no human involvement would be helpful because painting walls is a tiresome, boring, laborious, and dangerous procedure for humans [1].

Construction finishing tasks like painting include the use of potentially dangerous chemical substances. Such substances have an impact on human painters' health. The two primary painting techniques are roller painting and spray painting. The Egyptian market typically favors roller [2]. The scope of this project does not include the spray-painting robots with fixed robot arms that have been created for the automobile and home appliance industries [3].

Robots with the ability to move autonomously in enclosed places may be able to confine the application of roller painting to internal wall painting [4]. In Egypt, wall painting is thought to cover 40 million square meters each year. If the new robot can capture 10% of the painting business in 4 years, it translates to 100,000 square meters annually [5]. There will be a need for 50 robots each year if one robot can paint about 70 m2 per day and works 240 days per year. The next step is to manufacture robots that can either be rented to end users and painters for $50 per day or sold to a large building. The global market is anticipated to provide opportunities for product improvement and feature expansion [6]. As we shall show, there were not many trails used to construct wall painting robots [7]. We avoid using spray paint and concentrate on roller painting. Early experiments painted a room using a 500 kg heavy robot arm [8]. This is undoubtedly not a workable approach because the robot is immobile and has a small work area. Some ideas were put into practice in Malaysia and Italy; however, they were either sophisticated and heavy designs or ceiling-only designs [9]. A product with complete robot autonomy has not yet been created. At E-JUST encouraged the master student to construct an E-JUST painting robot, which operated but had a slow speed due to the adoption of a straightforward two-arm mechanism and stepper motors. In fact, as we shall take into account in this project, the necessary degrees of freedom should be carefully chosen. A robot with too many degrees of freedom is overly complicated and neither necessary nor useful [10].

Less degrees of freedom could limit the robot's range of motion and planning capabilities. The success of such a robot is largely due to its simplicity of design [11-16].

In this study, a novel painting robot that uses a roller to paint interior walls was implemented. The new design's primary requirements are simplicity, stiffness, stability, user-friendliness, light weight, speed, and affordability. Using a roller that receives paint from a pump, this robot will paint walls.

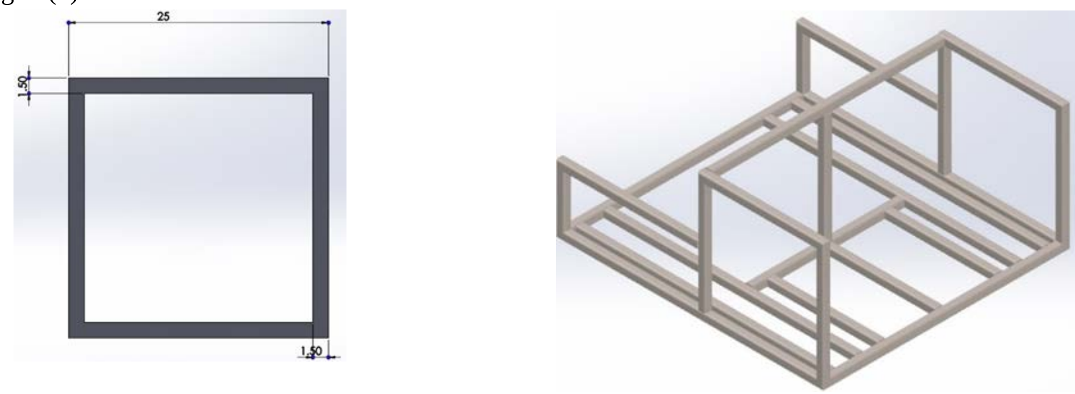
While the robot mobile base moves independently inside the room walls to complete the painting, the roller scans the wall vertically. The robot elevates a painting x-y stage to predetermined wall heights using a linear cascaded lift mechanism linked to a differential driving base. The x-y stage then uses its tip, which is equipped with a typical pump-fed roller, to scan a specific region of the wall.

When compared to the light x-y stage, the heavier lift mechanism is designed to experience less motion and thus less wear. The user interface and control of the robot are straightforward. The system performs well with a weight of - kg and a painting rate of m^2/hr., according to experiments. The robot's vertical scan takes (40) seconds, resulting in a painting pace of (5) m^2/h, and its 60 kg weight ensures portability for indoor applications.

The paper is organized as follows: the mechanical design and methodology show the wall painting robot design and the layout. The control algorithm presents the robot system architecture and the implemented control algorithm. Finally research conclusions.

2. Mechanical Design and Methodology

The base of the robot is made from steel because of its rigidity which reduces the vibration of the robot. The steel bar dimension (25 X 25 cm and 1.5 mm thickness). As shown in Fig. 1 (a) steel bar section. Base dimension (650mm length and 600mm width) is shown in Fig. 1 (b). After discussions with architectural engineers, it is concluded that the standard design of doors and height of the wall of the apartment. So that this paper considers the most suitable dimension for the robot as following as: Height: 2820 mm, Width: 600 mm and Length: 650 mm shown in Fig. 1 (b).



(a) (b)

Fig. 1. (a) Bar section, (b) Robot Base.

In this section, we will show the manufacturing of the three main parts of the robot which are Base manufacturing, Cascaded linear lift, and X-Y table (Fig. 2).

Fig. 2. X-Y table.

2.1 Base Design

The base is manufactured by a steel bar which is connected to form a base structure strong enough to withstand the stresses and forces of the robot on it and fits 4 wheels. As shown in Fig. 3.

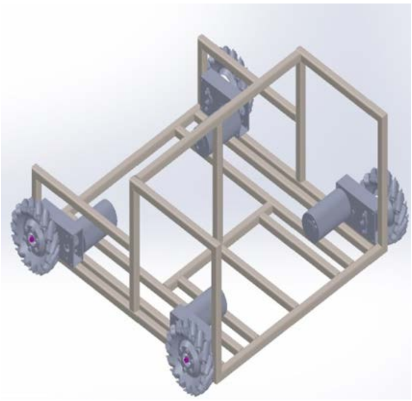


Fig. 3. Base Assembly

2.2 Wheel design

2.2.1 **Mecanum wheel**

Bengt Ilon, an engineer of the Swedish company Mecanum AB, devised and created the mecanum wheel in Sweden in 1975 [4]. The mecanum wheel works on the basis of a centre wheel that has several rollers positioned at angles all around its perimeter. Although the angle between the axes of the rollers and the central wheel might be any value, Fig. 4 illustrates that it is 45° in the case of a standard Mecanum wheel.

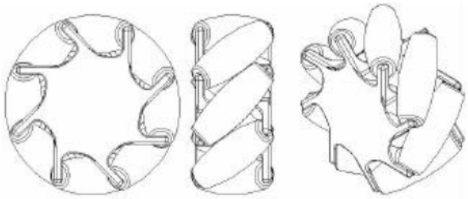


Fig 4. Mecanum wheel.

The omnidirectional wheel's profile is round because of the way the rollers are fashioned. A portion of the force in the wheel's rotating direction is translated into a normal force to the wheel direction by the inclined periphery rollers. The sum of these forces, which depend on the speed and direction of each wheel, can yield a total force vector in any desired direction, allowing the platform to move freely in that direction without shifting the wheel's orientation. A Swedish omnidirectional wheel has 3 DOFs composed of wheel rotation, roller rotation, and rotational slip about the vertical axis passing through the point of contact shown in Fig. 5.

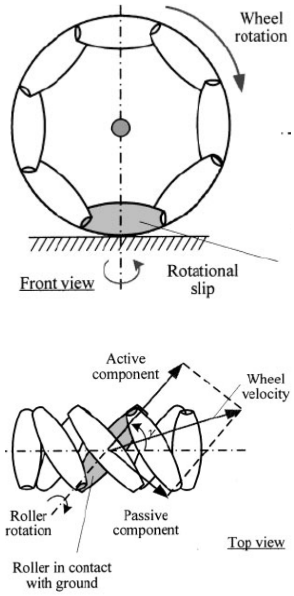


Fig. 5. DOFs in a Mecanum wheel.

The wheel velocity of an omnidirectional wheel can be separated into components in active and passive directions. While the passive component is perpendicular to the roller axis, the active component is oriented along the roller's axis that is in contact with the ground [5]. A force vector perpendicular to the wheel and a force vector along the wheel are produced while the wheel turns. The vehicle's direction of travel can be instantly altered using a single wheel rotation control.

A minimum of one roller and a maximum of two rollers must be in touch with the ground for a Mecanum wheel to be in rotation. The roller only makes at one point a little portion of its surface contact with the earth. Depending on the sensation of wheel rotation, the area of this surface moves across the roller from side to side. The traversing sensation of the contact surface will determine the direction of the traction force. This indicates that the traction force will be perpendicular to the roller axis when viewing the wheel from above. Each of the four Mecanum wheels has its own connection to the motor and is managed separately. The movable platform can travel forward, backward, sideways, and in any other desired direction or spin seen in Fig. 6 depending on the direction and speed of each individual wheel.

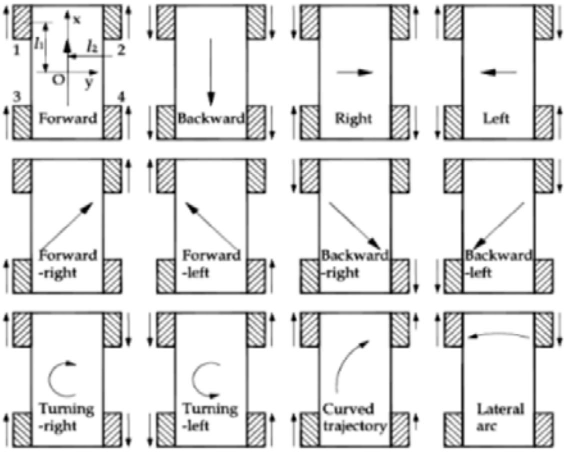


Fig. 6. Mecanum wheel motion.

2.2.2 Omni wheel

Omni-directional wheels are helpful since they may roll freely in two directions thanks to rollers that are positioned all the way around them. They can use rollers to roll laterally or like a regular wheel. useful in small areas and enables rotation in both directions without altering its alignment, as seen in Fig 7.

Fig. 7. Omni wheel motion.

2.2.3 Swerve wheel

A swerve drive is a system where the wheels can be freely directed in addition to being driven forward and backward. This indicates that in addition to being able to turn like a Skid Steer robot, the robot may go in any direction by adjusting its wheels, as seen in Figure 8.

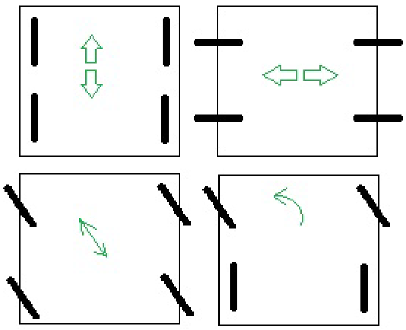
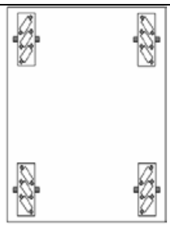
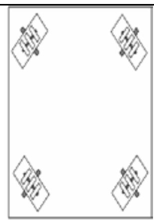
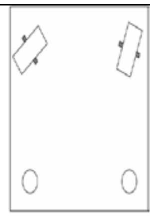


Fig. 8. Swerve wheel motion.

The following table 1 illustrates the comparison between three different types of wheels.

Table 1. Advantages and disadvantages of Mecanum, Omni wheel, and Swerve wheel.

Properties	Mecanum wheel	Omni wheel	Swerve wheel
Description	 Wheels with angled rollers.	 Wheels with straight rollers.	 Independently steered the drive module.
Advantage	• Easy to control; compact design; high load capacity; reduced speed and pushing force when going diagonally	• Lightweight; compact; easy to operate; requires less pushing force and speed when travelling diagonally	• Steering with a lot of friction and scouring; heavy and substantial construction; complex to program and regulate.
Disadvantage	• High sensitivity to floor irregularities; Discontinuous wheel contact; Very complex conceptual design	• More conceptual complexity; Variable driving radius or discontinuous wheel contact; Sensitiveness to floor irregularities; Reduced traction	• High friction and scouring when steering; Heavy and hefty construction; Complicated to program and regulate.

According to the previous comparison, the Mecanum wheel is more appropriate for a wall painting robot than the Omni wheel since it can support heavier loads and is more stable because a smart wall painting robot requires more stability.

2.3 Cascaded linear lift

We dedicate the concept of the cascaded linear from the forklift. So that the design of the cascaded linear has the following dimensions: 1000mm and Width: 300mm to be suitable for the motion of the robot during painting the wall (3m height). Because it was found that the RMI (Rack Manufacturers' Institute) defines the height-to-depth ratio for a rack row as "the ratio of the distance from the floor to the top beam level divided by the depth of the frame.'' This ratio cannot exceed 6 to 1.

2.4 X-Y table

It had to be the horizontal movement that allows paint to facilitate the process of Paint. X&Y table is the same component and perpendicular to each other this is the X-Y table construction shown in Fig. 9. The parts of the X-Y table are 2 Motors, 2 Belts, Nut, 8 Wheels, and 2 plates.

Fig. 9. X table.

Finally, the following Table 2 demonstrates the painting robot specification, and the overall assembly demonstrated in Fig. 10.

Table 2. The wall painting robot specification.

Dimension	650(L) X 600(W) X 120(H), Overall 2820 (H)
Weight	60 kg
Lift capacity	20 kg
Degree of freedom	7 degree of freedom
Driving mode	Differential
Direct of moving	360°
Sensor	Ultrasonic sensor
Interface	Bluetooth module
Communication	Mobile
Controller	Adruino mega 2560
Power	Power supply 12 V DC

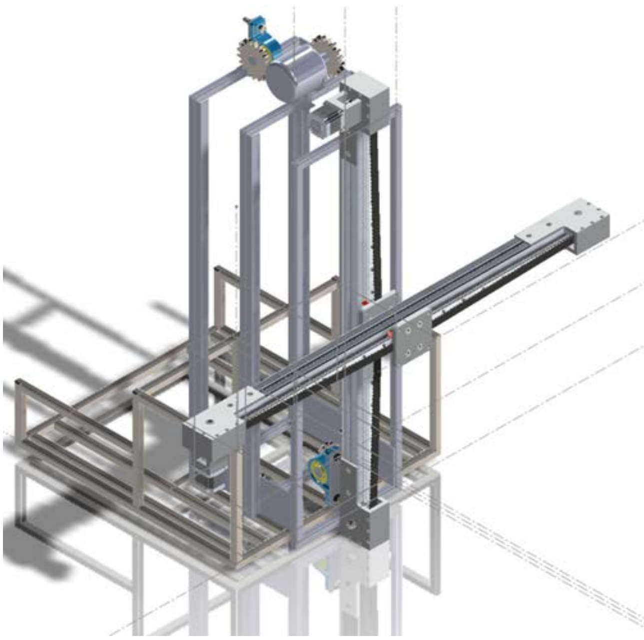


Fig. 10. The robot assembly

3. Control algorithms

Fig. 11 shows the employed control of architecture. It is divided into 2 main levels: task generating and scheduling and task executing. As the name implies, first-level control stores the required tasks and generates them in the form of high-level commands according to the specific schedule. Those high-level commands are understandable by human logic. According to the wall roller contact is in the whole painting process and serves as contact force feedback from operational space.

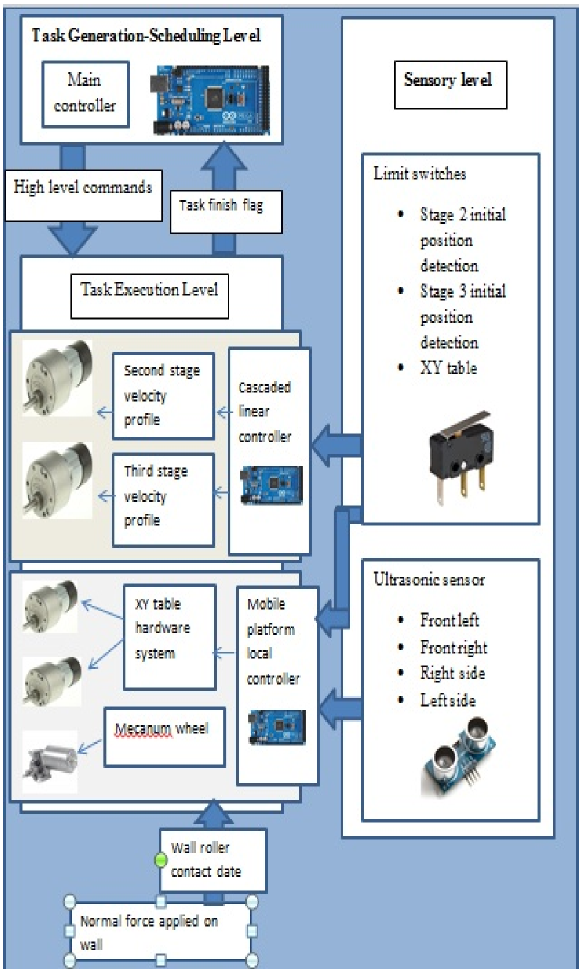


Fig. 11. System Architecture.

The wall painting robot is controlled by implementing the control algorithm flowchart shown in Fig. 12. The procedure starts by homing the robot; that is moving to the home position. Home position requires moving first to the reference position in the step called referencing. At this position, the cascaded linear has the initial configuration that is suitable for painting based on the initial position conditions of the painting roller. The robot will take the position before starting painting. Firstly, robots will move forward until sensor 1 (Z1) and sensor 2 (Z2) is equal to

30 Cm. Second, adjust the robot accurately from the left or right side (X or Y). Which sensor in the left or right that near the wall; the robot will move towards near wall until reach to to 10 Cm from the wall.

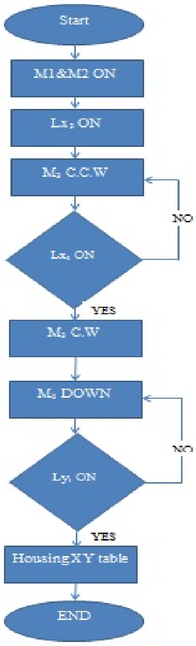


Fig. 12. Control algorithm flow chart.

The robot as shown in Fig. 13 will reach the max position of the wall by turning on M1 and then M2. The robot will start to paint the wall by turning motor 3 (x stages) on. Motor 3 will move C.C.W and then C.W. to the initial position. After this step, motor 4 (y stage) will turn on and then repeat the previous step of motor 3. When the y-stage reaches max position the robot will house the X-Y table.

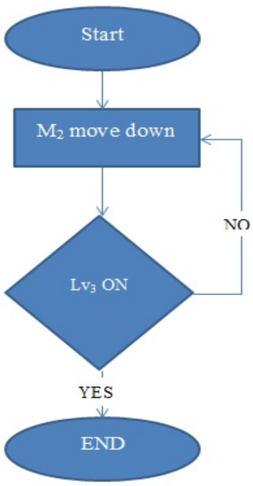


Fig. 13. Flow chart subroutine 1.

After completing the robot painting of the wall of the third stage; motor 2 of the cascaded linear will turn on to the second stage and repeat the painting process as shown in Fig.14.

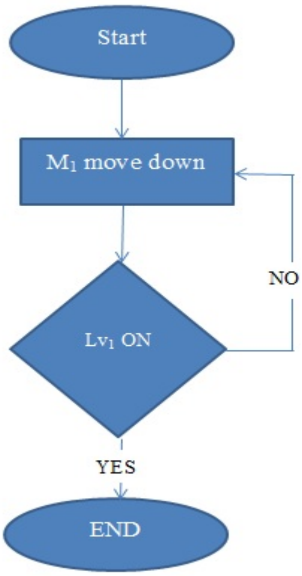


Fig. 14. Flow chart subroutine 2.

The procedure starts by homing the robot; that is moving to the home position. Home position requires moving first to the reference position in the step called referencing. At this position, the cascaded linear has the initial configuration that is suitable for painting based on the initial position conditions of the painting roller. The robot will take the position before starting painting. Firstly, robots will move forward until sensor 1 (Z1) and sensor 2 (Z2) is equal to 30 Cm. Second, adjust the robot accurately from the left or right side (X or Y). Which sensor in the left or right that near the wall; the robot will move towards near wall until reach to 10 Cm from the wall

The robot as shown in Fig. 13 will reach the max position of the wall by turning on M1 and then M2. The robot will start to paint the wall by turning motor 3 (x stages) on. Motor 3 will move C.C.W and then C.W. to the initial position. After this step, motor 4 (y stage) will turn on and then repeat the previous step of motor 3.

When the y-stage reaches max position the robot will house the X-Y table. After completing the robot painting of the wall of the third stage; motor 2 of the cascaded linear will turn on to the second stage and repeat the painting process as shown in Fig.14.

4. Conclusion

This paper presents the mechatronics design of a wall painting robot. The new design is simple and stable. The robot has a mobile base to move autonomously in the house. Attached to the base is a vertical 2-stage linear cascade slide. An X-Y stage is attached to the end of the slide to scan for painting in the selected area. This design reduces the wear of the vertical slider since most motion is made by the X-Y stage. The robot can paint at a rate of 5 m^2/hr while is comparable to that of human painting. The robot was built with the drive modules and software for autonomous operation of the robot. An interface through an android mobile phone has been made to facilitate the operation or taking orders from the remote

References

[1] Ilon, B.E., “Wheels for a course stable self- propelling vehicle movable in any desired direction on the ground or some other base”, US Patent and Trademarks office, Patent 3.876.255, 1975.
[2] Song, J.B., Byun, K.S., “Design and Control of a Four-Wheeled Omnidirectional Mobile Robot with Steerable Omnidirectional Wheels”, Journal of Robotic Systems, 21(4), 2004, pp. 193-208.
[3] A. Warszawsky, Y. Rosenfeld, “Robot for interior finishing works in building: feasibility analysis,” J. Const. Eng. Manage., vol.120, no.1, pp. 132-151, 1994.
[4] B. Kahane, Y. Rosenfeld, “Balancing human-and-robot integration in building task,” Comput. Aided Civil and Infrastructure Eng., vol.19, no.6, pp. 393-410, Aug. 2004.
[5] B. Naticchia, A. Giretti, A. Carbonari. “Set up of an automated multi-color system for interior wall painting,” Int. J. of Advanced Robotic syst., vol.4, no.4, pp.407-416, Nov. 2007.
[6] M. De Grassi, B. Naticchia, A. Giretti & A. Carbonari, “Development of an automatic four color spraying device carried by a robot,” in the 24th International Symposium on Automation and Robotics in Construction, Sendai, Japan, 2007, pp.235-240.
[7] B. Naticchia, A. Giretti, A. Carbonari, “Set up of a robotized system for interior wall painting,” in the 23rd International Symposium on Automation and Robotics in Construction, Tokyo, Japan, 2006, pp.194-199.
[8] I. Aris, A. K. Parvez Iqbal, A. R. Ramli & S. Shamsuddin, “Design and development of a programmable painting robot for houses and buildings,” J. Universiti Teknologi Malaysia, vol. 42, no.1, pp. 27-48, Jun. 2005.
[9] B. E. Teoh and S. V. Ragavan, “PAINTbot-FPGA Based Wall Painting Service Robot Prototype,” in the Recent Advances in Intelligent Computational Systems, Trivandrum, India, 2011, pp.777-782.
[10] M. Sorour, M. Abdellatif, A. Ramadan and A. AboIsmail, “Development of Roller-Based Interior Wall Painting Robot”, Proceeding of the ICAM ,Venice, Italy,pp:1785-1792, 2011.
[11] Kyung-Seok Byun, Sung-Jae Kim ; Jae-Bok Song, Design of a four-wheeled omni-directional mobile robot with variable wheel arrangement mechanism, ICRA pp: 720-725, 2002.
[12] M. Udengaard and K. Iagnemma, Analysis, Design and Control of an Omni-directional Mobile Robot on Rough Terrain, Journal of Mechanical Design, Vol. 131, ASME Transactions, 2009.
[13] M. H. Ghasemi, A. H. Korayem, S. R. Nekoo, and M. H. Korayem, “Improvement of position measurement for 6R robot using magnetic encoder AS5045,” J. Comput. Appl. Res. Mech. Eng., vol. 6, no. 1, pp. 11–20, 2016.
14] K. Alipour, M. Ghiasvand, and B. Tarvirdizadeh, “Dynamical formation control of wheeled mobile robots based on fuzzy logic,” J. Comput. Appl. Res. Mech. Eng., vol. 6, no. 2, pp. 79–91, 2016, doi: 10.22061/jcarme.2017.600.
[15] M. H. Falsafi, K. Alipour, and B. Tarvirdizadeh, “Fuzzy motion control for wheeled mobile robots in real-time,” J. Comput. Appl. Res. Mech. Eng., vol. 8, no. 2, pp. 133–144, 2019, doi: 10.22061/jcarme.2018.2204.1205.
[16] M. Mohammadi, R. Dehghani, and A. R. Ahmadi, “Robust adaptive projection-based control of a constrained quadrotor with two manipulators,” vol. 11, no. 2, pp. 351–364, 2022, doi: 0.22061/JCARME.2021.5860.1741.