The Survey of Self Driven Wall Painting Robots for Interior and Exterior Applications

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Abstract.

The development of autonomous wall painting robots represents a significant advancement in construction automation, enhancing efficiency, safety, and quality. These robots utilize various technologies, including vision systems and automated controls, to perform painting tasks with precision. Implementing robotic systems for exterior wall painting can significantly lower labour costs and enhance worker safety by minimizing exposure to hazardous conditions associated with manual painting. A feasibility study indicates that such robots can improve productivity and quality in multi-dwelling apartment maintenance, making them a viable solution for the construction industry. This research paper discussed the different research work on Wall painting mechanism with different challenges, future of autonomous wall painting robot and their applications in real world.

Keywords.

Spray-painting, wall painting robot, Robo painter, automated painting system.

1. INTRODUCTION

Robots represent one of the most extensively employed automation techniques across various industries, including heavy manufacturing, healthcare, and intelligent library systems. The discipline of robotics encompasses a multidisciplinary approach to the creation of machines that emulate and substitute human labour, integrating fields such as mechanical engineering, electrical and electronic engineering, artificial intelligence, and computer vision. The advent of automatic wall painting robots has emerged as an essential requirement over the past decade, driven by the increasing verticality of structures and the proliferation of skyscrapers.

The implementation of such solutions would contribute to the mitigation of occupational hazards stemming from environmental conditions encountered by workers, including severe winds, storms, and the risk of falls. In contemporary society, nations around the globe are experiencing accelerated development, with numerous edifices being erected on a daily basis. The task of painting walls is of considerable importance, extending beyond mere aesthetic enhancement of interiors, and can also be conceptualized as an integral component of the construction process. Nevertheless, data from the Bureau of Labour Statistics revealed that approximately 2.9 million nonfatal workplace injuries were recorded by private industry employers in 2015, with an incidence rate of 3 cases per 100 equivalent full-time employees.

The manual application of paint to walls and ceilings is characterized by its repetitive nature, considerable time investment, physical demands, and inherent dangers. On one side, the numerous health-related disadvantages associated with human labour advocate for the automation of this process. Conversely, the employment of painters is anticipated to increase by 11% from 2019 to 2029, as reported by the U.S. Bureau of Labour Statistics, necessitating an augmentation of 57,600 positions for painters within this timeframe in the United States alone.

The tasks involved in industrial and residential painting are characterized by significant physical exertion and temporal demands, often necessitating repetitive motions that require sustained attentiveness; this circumstance may engender discomfort or anxiety. Furthermore, the paints utilized in these processes comprise hazardous volatile organic compounds, with prolonged exposure to such substances potentially resulting in irritation, nausea, and detrimental effects on the pulmonary, renal, and hepatic systems. These health and safety hazards evidently underscore the imperative for research into wall painting automation through robotic systems. The probable process of autonomous wall painting by robot is shown in figure 1.1.

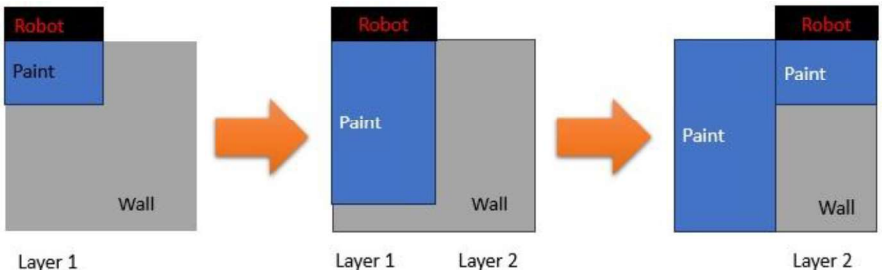

Figure 1.1. Autonomous wall painting process

The activities within the construction sector are characterized by a relentless dynamism, as advancements in building projects and innovations are experiencing a notable escalation. Scholars are diligently engaged in the examination of the obstacles presented by elevated structures, large storage facilities, irregular ground surfaces, and challenging terrains, while simultaneously seeking procedural solutions to mitigate these issues. The conventional methodology of wall painting is gradually being supplanted by emerging concepts cantered around the development of robotic systems for wall painting. Contemporary innovations, such as wall-traversing robotics, have been thoroughly documented; these robotic systems possess the capability to adhere seamlessly to vertical surfaces, thereby facilitating optimal coverage of wall areas. The Probable work flow of Autonomous wall painting robot is shown in figure 1.2.

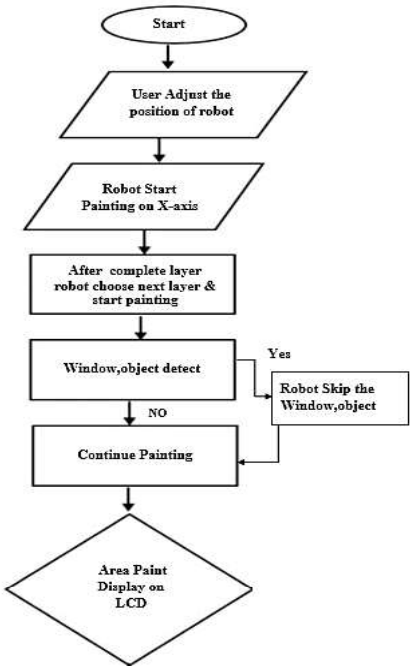

Figure 1.2. Probable Flow diagram of Autonomous Wall Painting robot

2. LITERATURE REVIEW

The research paper [1] focused on presenting experimental results of a new spray paint algorithm that reduces joint torques needed for painting surfaces. The study emphasizes maintaining constant velocity over precise orientation of the paint gun. The empirical data obtained through real-world experiments validates the algorithms' effectiveness in reducing energy consumption by 50% or increasing the speed of the paint gun by more than 50%.

The research work [5] focused on the development of autonomous painting machines to address the increasing demand for painting jobs in the real estate market, where human labour is costly and time-consuming. Sarour et al. have explored a roller approach with omni-wheels for robotic arm systems, utilizing ultrasonic sensors and Arduino Mega boards for successful paintwork at a rate of 0.101 hour/m2.

Factors that limit the adoption of robotics in the construction industry mentioned in the research [11]. It included challenges such as workforce challenges, economic challenges, cultural challenges, industry-intrinsic challenges, and research development challenges. The study combined a qualitative analysis through focus group discussions and a quantitative analysis to rank and validate the identified factors.

Some researchers [15] discussed various existing wall painting robots like Robo Painter, AGWallP, and others that utilize different mechanisms for automated painting tasks. These robots use technologies like ultrasonic sensors, IMU, Raspberry Pi controllers, and spray paint systems to achieve efficient and precise wall painting capabilities.

The paper [21] focuses on the challenges in similitude analysis for electromechanical coupling systems, highlighting the complexity of such systems compared to single-energy type systems. Traditional similitude analysis methods are limited in addressing the complexities of electromechanical coupling systems due to their involvement with multiple energy types and variables.

The manuscript [22] underscored the imperative for a multifaceted and computationally efficient algorithm for path planning in the realm of collaborative robotic car-painting. Current methodologies employed for trajectory generation within industrial painting automation systems utilizing robotic technology are notably labour-intensive, thereby necessitating the investigation of CAD-based approaches for trajectory generation. The proposed methodology emphasizes the decoupling of collision avoidance from coverage path planning by capitalizing on the bidimensional structure inherent to the problem.

The researchers [24] includes references to various studies related to automatic painting robots and spray-painting robots. It discusses the need for automation in wall painting due to the repetitive, stressful, and hazardous nature of the process. It highlights the importance of designing cost-effective spray-painting robots for painting irregular workpieces with highly contoured surfaces.

The manuscript [25] examines the obstacles encountered in the domain of shipbuilding, with a particular emphasis on the perilous endeavour of applying paint to the external surfaces of vessels by human operatives at elevated heights utilizing painting apparatus. Scholars have been engaged in the innovation of mobile robotic systems capable of functioning on vertical surfaces to mitigate these difficulties, with suction-based mobile robots being extensively implemented, albeit they exhibit constraints in mobility during the painting process. The proposed automatic painting robot in the study utilizes a permanent magnet wheel and vision system to autonomously move on the outer plate of the ship for painting tasks, aiming to overcome the risks associated with manual painting processes.

3. CHALLENGES OBSERVED

The researchers [3] discussed the challenges related to the complex calculations and analysis involved in determining the position and orientation of the end effector of a spray-painting robot. It highlights the complexity of the calculations, which contain many variables even in an element of a matrix, necessitating the use of MATLAB software for simplification.

The challenges also include the need for forward and inverse kinematic calculations using Denavit-Hartenberg (D-H) methods, which are essential for accurate spray-painting patch generation and joint angle calculations. Additionally, the paper addresses the challenge of determining the distance between joints and calculating the angles for effective spray-painting tasks.

Repeat painting multiple times for quality due to splashing in traditional methods is another challenge observed by the researchers [4]. The limitations of linear and Z-shaped painting trajectories in terms of efficiency and continuity between coatings. The complexity of realizing spiral trajectories and the difficulty in controlling painting quality with such trajectories.

The paper [5] discussed challenges such as the need for a robust mixing device for multi-colour setup in the AGWallP system, as the current prototype is designed for a single-color system only. Another challenge highlighted is the initial consideration of using an IR sensor setup for perceiving white plastered walls, which was found to be error-prone and limited in offering a variety of templates for users, leading to the adoption of image processing tools with OpenCV2 for better accuracy and flexibility.

Some researchers [8] mentioned the challenges related to the absence of certain features in the current paint simulator, such as surface properties like absorption, paint runs, and the ability to vary ambient lighting, which are planned for future work. Another challenge highlighted is the need to reduce latencies in live processing to enhance user experience, as latencies can occur due to processing time and the UAV's limitations in painting speeds compared to a human hand.

The most important challenges discussed by the researchers [9] include the hazards posed to human painters by painting chemicals, leading to eye and respiratory problems, as well as the repetitive and time-consuming nature of manual painting tasks. Another challenge highlighted is the need to reduce or eliminate human exposure to hazardous environments during painting activities, emphasizing the importance of safety in construction tasks.

The researchers [10] discusses the challenge of the Iterative Closest Point (ICP) algorithm getting trapped in local minima during pose estimation, which was addressed by combining it with a Genetic Algorithm (GA) to search for the global minimum and reduce pose estimation errors. Another challenge highlighted is the lack of robustness of ICP to local minima, which was resolved by integrating GA to optimize pose error and prevent local minimum entrapment.

The challenges discussed in the paper [11] include workforce challenges like lack of continuous training and unskilled workforce, economic challenges such as high initial capital investment and low return on investment, cultural challenges like aversion to change and job security concerns, industry-intrinsic challenges such as a fragmented industry and intense competition, and research and development challenges like low investment in research and development and weak innovation culture.

The researcher [24] discusses the challenges faced in shipbuilding, particularly in the painting of the outer plate of ships, which is considered dangerous due to human workers operating at high altitudes with painting equipment.

4. FUTURE OF AUTONOMOUS WALL PAINTING ROBOT

The future scope of autonomous wall painting robots is promising, driven by advancements in robotics, artificial intelligence, and user interaction. These robots can revolutionize not only the painting industry but also public art and expression.

4.1. Technological Advancements

- Navigation and Control: Autonomous robots like those utilizing fuzzy incremental controllers can effectively navigate walls, ensuring precise movement and painting coverage.
- Automated Painting Systems: Robots equipped with vision systems and GPS can generate painting plans and execute them autonomously, enhancing efficiency and accuracy in large-scale projects.

4.2. Applications in Public Art

- Interactive Art: WallBots allow artists and activists to engage with public spaces creatively, enabling low-cost, DIY art installations across various surfaces.
- Artistic Techniques: Robots that mimic human painting techniques, such as underpainting and refinement, can produce intricate artworks, expanding the creative possibilities for artists.

While the potential for autonomous wall painting robots is vast, challenges remain in ensuring artistic quality and public acceptance, which will require ongoing research and development.

5. METHODS, FINDINGS AND LIMITATIONS

Table 5.1 Comparative analysis of Different methods, findings and their limitations

Author	Method Used	Findings	Limitations
Y. Mahulkar, A. R. Kalbande [24]	Electrostatic spray-painting technique	An Automatic Wall Painting Robot to achieve low-cost painting equipment.	1) The hazards caused by painting chemicals to human painters 2) Repetitive and time-consuming method.
Y. Song, J. Wu [21]	Similitude analysis method considering electro-mechanical coupling effect	The implementation of a spray-painting robotic system under optimal conditions is conducted, thereby addressing issues related to motor inertia and resistance distortion.	Influencing the interrelations among variables and possibly altering the comparative analysis of dynamic performances.
V. TADI, A. ODRY [18]	ZED Depth Sensor for Painting Robot Vision	Detecting and extracting surfaces and objects for painting robot	The formation of a marked shadow on the surface, which restricts the camera's visibility and may yield a deficient depth image.
Y. Ma, N. Xi [12]	Mobile painting Technique	The smooth implementation of simulation process demonstrates that the optimized structure parameter can fulfil the task requirement	Need for a large number of discrete points for obtaining good results
A. Anwar, Z. Li [10]	Cross Correlation Method	The findings were derived from the collected point clouds of the lateral automotive components.	Required more time than the actual processing due to the parallel implementation
B. Sai Krishna, Chandrashekar. M [9]	Movable painting using Roller fed with liquid paint	The opportunity to reduce or eliminate human	The components involved in painting may entail significant dangers for human artists, comprising problems concerning visual health and respiratory function.
A. Vempati, H. Khurana [8]	Smoothing planner for generating smooth trajectories for UAV	The implementation of a virtual reality interface to delineate an artistic undertaking.	does not provide complete flexibility for users to accurately modify the target.
M. Kamel, N. Stilinovic [7]	Critical UAV operations are executed on board	Autonomous spray painting using unmanned aerial vehicles (UAVs) includes area filling and customizable line painting on 3D surfaces.	The need for a dense 3D model of the target surface for painting quality,
U. Bawane, R. Bakkar [6]	Computer control system activated by operator pressing a switch on a control panel	The Automated Wall Painting bot facilitates the minimization of human engagement and the	The challenges in planning paint strokes that continue throughout different geometric primitives on

		reduction of expenditures associated with painting apparatuses.	surfaces and the inability of continuous robot motions.
M. Sorour [2]	CAD model of the fully functional wall painting robot	Presented endows several achievements in terms of total robot mass and painting rate as compared to existing literature	The restriction of the painting arm's motion laterally to the width of a maximum of paint strips in either direction from the robot centreline.

6. CONCLUSION

The development of autonomous wall painting robots has shown significant promise in enhancing efficiency, safety, and quality in painting applications. Various designs and technologies have been explored, leading to innovative solutions for both interior and exterior wall painting. A wall-following robot utilizes a fuzzy incremental controller for navigation, demonstrating effective wall tracking and movement control. Automated Painting Systems: Robots equipped with vision systems and GPS can autonomously generate painting plans and execute them, ensuring precise coverage of surfaces. Robots like the automatic paint spray system use machine vision to assess wall conditions, allowing for adaptive painting techniques that enhance uniformity and reduce waste.

The conceptual design for exterior wall painting robots indicates substantial cost savings and improved safety for workers, particularly in high-rise buildings. The use of multiple drones for graffiti and mural painting showcases the potential for rapid and efficient painting processes, which can be adapted for commercial applications. While these advancements present numerous benefits, challenges such as system complexity and initial setup costs remain. Future research may focus on optimizing these systems for broader applications in construction and maintenance.

7. REFERENCES

[1] P.Johan , J.Gunnar, and J.T. Gravdahl , “Optimal Paint Gun Orientation in Spray Paint Applications—Experimental Results” IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING, VOL. 8, NO. 2, APRIL 2011.

[2] M. Sorour, “RoboPainter-A Detailed Robot Design for Interior Wall Painting”, Conference: IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO-2015).

[3] O. P. Guleja, “Six DOF Spray Painting Robot Analysis”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, DOI: 10.15662/IJAREEIE.2015.0409061 ,9 Sep 2015.

[4] W. Li, W. Cui, Y. Zhang, C. Yu, “Trajectory Analysis of Painting Robot on Building Wall”, method of simulating the motion of manual painting was selected. The 11th International Conference on Computer Science & Education (ICCSE 2016) Nagoya University, Japan August 23-25, 2016.

[5] K. Madhira, S. Mehta, R. Bollineni, D. Kavathia, “AGWallP -Automatic Guided Wall Painting System”, Nirma University International Conference on Engineering (NUiCONE) 2017.

[6] U. S. Bawane, “Automatic Wall Painting Machine”, International Journal of Emerging Technologies in Engineering Research (IJETER), Vol (6) ISSN 2312-4315 Feb 2018.

[7] A. Sai Vempat, “PaintCopter: An Autonomous UAV for Spray Painting on Three-Dimensional Surfaces” IEEE ROBOTICS AND AUTOMATION LETTERS, VOL. 3, NO. 4, OCTOBER 2018.

[8] A. Sai Vempati, H. Khurana “A Virtual Reality Interface for an Autonomous Spray-Painting UAV” IEEE ROBOTICS AND AUTOMATION LETTERS, VOL. 4, NO. 3, JULY 2019.

[9] B Sai Krishan, “Fabrication of Automatic Wall Painting Machine”, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, 2019.

[10] W. Lin, “Recognition and Pose Estimation of AutoParts for an Autonomous Spray Painting Robot”, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 15, NO. 3, MARCH 2019.

[11] L. Oyedele, “Robotics and Automatic Systems in a Construction”, Understanding Industry Specifics Challenges for Adoption, Journal of Building Engineering, Vol (45) Nov 2019.

[12] Ye. Ma and Ning Xi, "Task-Oriented Design Optimization for a Mobile Painting Robot", Proceeding of the IEEE International Conference on Robotics and Biomimetics Dali, China, December 2019.

[13] B. S, Madhavan, K, A. Jinushia R, Thandapani T, "Automated Exterior Wall Painting Robot Using Raspberry Pi", 6th International Conference on Advanced Computing & Communication Systems (ICACCS) 2020.

[14] J. C. Virgolino Soares, "Autonomous Navigation System for a Wall-painting Robot based on Map Corners" 2020 IEEE.

[15] R. K Megalingam, V.P Darla Chaitanya Sai Kumar Nimmala, "Autonomous Wall Painting Robot", robotic painting was introduced to improve the accuracy, efficiency and to reduce the cost. 2020 International Conference for Emerging Technology (INCET) Belgaum, India. Jun 5-7, 2020.

[16] R. Kumar S, Kaviarasu S, "Self-Operating Paint Bot", A 2-dimensional axes arms are used to paint the wall. 5th International Conference on Devices, Circuits and Systems (ICDCS),2020.

[17] S. Danthala, "Automatic Spray-Painting Robot Using Regression Method", International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-5, January 2020.

[18] V. Tadic, "Application of the ZED Depth Sensor for Painting Robot Vision System Development" This work was supported by the European Union under Project IEEE Access vol (9),2021.

[19] A. Munner, "Design and Implementation of Automatic Painting Mobile Robot", IAES International Journal of Robotics and Automation (IJRA), Vol (59) ISSN 0921- 8890 March 2021.

[20] M. Okwu, L. Tartibu ,O. B. Otanocha , D. R. Enarevba, "Development of a Modular Wall Painting Robot for Hazardous Environment", International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD), 2021.

[21] Y. Song, J. Wu, Z.Liu , B.Zhang , and T.Huang, " Similitude Analysis Method of the Dynamics of a Hybrid Spray-Painting Robot Considering Electromechanical Coupling Effect" IEEE/ASME TRANSACTIONS ON MECHATRONICS, VOL. 26, NO. 6, DECEMBER 2021.

[22] K. ZBISS, A. KACEM, "Automatic Collision-Free Trajectory Generation for Collaborative Robotic Car-Painting" date of publication January 19, 2022.

[23] D.Gleeson, S.Jakobsson, N.Sandgren, and B.Lennartson, "Generating Optimized Trajectories for Robotic Spray Painting" IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING, VOL. 19, NO. 3, JULY 2022.

[24] Y. Mahulkar, A. Kalbande, A. Nikam, A. Katare, "A Review on Low-Cost Automation Spray Painting Robot" International Research Journal of Modernization in Engineering Technology and Science, Volume:04/Issue:06/June2022.

[25] C. Cho, "A study on Automated mobile painting robot with permanent magnet wheels for outer plate of ship" Department of automobile, Yeungnam college of science & technology korea, Conference: Robotics (ISR), 2013 44th International Symposium, October 2013.