Robot Nano Spray Painting - A Review

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Abstract. Since 1970s, robotic painting has been widely adopted to manufacturing and automobile industry, because of its many advantages over manual painting in its high efficiency, economy and keeping workers away from hazardous chemicals. During the automated painting process, the spray gun, the end-effector of the painting robot, is guided to paint the targeted surface along the planned trajectories. Nano-sized additives are placed in the latex paint to enhance the quality of paint. The purpose of this study is twofold: examine the trajectory planning of robot and discuss the most influential parameters to increase the quality and lifetime of paint. Multiple databases were searched for literature and limiting to last ten years. The keywords selected for the search were a combination of the Paint thickness, Robot Spray Painting, Trajectory planning, Simulation, Nano Paint, Characteristics of paint, State of the art technologies. From the literature survey, few works were carried out using the robot paint and no work was conducted using the CNT based Nano paints and analysing the environmental characteristics, surface characteristics are very limited. This study will identify the factors that enhance the paint characteristics and will be useful for coating and paint industry. The factors like distance, pressure and speed are considered and the parameters like surface roughness, thickness and film adhesion is considered. To optimize the control parameters to improve the quality of Robot Nano spray paint coating by Robot Trajectory planning. Examine the control parameters to increase life time of painting and shining characteristic in current scenario of industry.

1. Introduction

In an era dominated by globalization, quality and cost are the most acute factors for any industry. Few key stages in entire manufacturing process are of utmost importance as it projects the quality of the product painting in automobile industry. Robots have been used in the automated painting application for many decades now [1-4]. The use of robots for painting operations is an alternative as a means for automation and quality improvement. Jobs which require precision and accuracy are done by robots. In automobile and aerospace industry, robots will be utilized for many operations like assembly parts, material handling and so on. The Large industries will go for robots on the factory floor for huge benefits as robots are capable of performing complex operations. Jobs like manufacturing, assembly, paint job, etc. are done by robots [5-8]. The frame of the car is welded together by robots, it has to be just perfect, and same is the case with paint job, assembly. the parts of the vehicle where humans cannot reach easily is done by machines like installing windscreen from inside, installing dashboard are some of the jobs done by robots.
Also, painting, coating or applying sealant on large framing parts or fuselage are not possible with manual painting, because of the complexity and size of the parts. By installing rails on robotic arms, huge workspace can be covered a distance from 30 to 40 feet, and more heights [9-14]. Also, industrial robots are able to paint uniformly with consistencies throughout the surface without leaving any drips or overspray. Design of experiment techniques had been considered for experimentation. Design of experiments is about how you are structuring your study. It typically refers to experimental methods (randomized controlled trials) or quasi-experimental methods (e.g., natural experiments). The design helps determines what level of internal and external validity is possible in a well-run study (and there are many practical factors that can mess this up). Design of experiments is an attempt to get the maximum information out of the fewest cases [15-18]. I think there is also an attempt to isolate effects, to set up the experiment so that variables that are not of interest do not affect the results. With least number of experimental runs an optimum design with best parameters can be produced. By utilizing statistical analysis, the number of experiments can be reduced, time and money can be saved. The mathematical model and correlation between input and output parameters can be be generated [19-24]. Minitab software is utilized to plot the interaction effects between input and output parameters and generate equations. Nano Coating is a new, cutting-edge sealant technology that is being used the automotive industry. Most Nano Coating is an acrylic based coating that has been designed to protect your vehicles' paint, while providing amazing gloss finish [29-32]. Nano paint is super-hydrophilic or hydrophobic which is formed by nano sized molecules. It can coat with a thickness below 100 nm or for coatings with a grain size below 100 nm. It has basically two parameters. First is composition of coating's chemistry should be in nano scale and the second is coating layer should be in nanometre sizes. Corrosion resistance, scratch, strain or water repellence and transparency are key features of nano paint. Nano Coatings employed to modify the properties of a surface or substance. Nano paints are liquid or solid in form. They are used to protect, seal, or colour the surface or substance. Nano particles used in nano paints and coatings have metabolic properties. Nano coatings are penetrative in nature and they have characteristics such as scratch resistance, high hardness, and resistance to bacteria [33-36]. These characteristics make them durable and high-performance coatings. Nano paints and coatings are largely applied in industries such as marine, automobile, warships, hospitals, oil & gas, electronics & optics, biomedical, packaging, and aerospace. Based on type of nanoparticle used, the nano paints & coatings has been divided into nano ZNO, nano-TiO2 (titanium dioxide), nano silver, nano-SiO2 (silicon dioxide), carbon nanotubes and graphene. Coatings improve durability, reliability, resistance to erosion and sliding, surface quality, UV resistance, and thermal insulation [37-40].

2. Methodology
For literature, multiple databases like IEEE, science direct were explored by limiting to last ten years from 2010 to 2019. The keywords selected for the search were a combination of the Paint thickness, Robot Spray Painting, Trajectory planning, Simulation, Nano Paint, Characteristics of paint, State of the art technologies. The obtained papers are cut down to 40 by scrutinizing title, abstract, conclusion and finalized with more appropriate and relevant work in papers.

By using ABB IRB 1410 an industrial robot the painting process will be carried mentioned in below figure. A specially designed end effector of high-volume low-pressure spray gun is utilised. The capacity of payload of end effector of robot is 5kgs and having of work volume of 1.45m. The updated IRC5 controller is used as IRB 1410 robot controller. The software version 5.13.03 had inbuilt controller to program in offline mode. The spray gun is one of the most key components in paint accomplishment process. This paint gun gives maximum transfer ability and atomization efficiency. This gun having with stand pressure of 3-4bar, gun is separated by a pressure pot and storage of paint tank.
3. Results and Discussion

All the forty papers are reviewed and divided into four major categories based on work processed in the paper. The categories are trajectory of robot, robot spray paint, nano particles and miscellaneous. Spray painting process by robot will help to enhance product quality, provide clean environment, reduce cost and labour. Any complex parts of any shape and size can be coated efficiently. Trajectory describes about degree of freedom (DOF), acceleration, velocity and position commands. The trajectory of the paint and painting time affects the thickness of paint. By utilizing nano materials in spray painting process the paint quality can be enhanced.

3.1. Robot Paint

By utilizing spray painting process by robot will help to enhance product quality, provide clean environment, reduce cost and labour. Complex parts of any shape and size containing uneven shapes, contoured and curved surfaces can be coated efficiently without runs. Finding out the influential parameters and optimizing them are the most critical aspects of the automated robot painting process. Javad Jassbi [1] studied on enhancing paint quality and reducing the defects by utilizing neural networks technology. They utilized two neural networks models, the first prediction model gives the film thickness for 10 input variables and dry film thickness for 12 input variables. On other hand the second predicting model gives uniformity of film thickness by standard deviation and averaging methods. The results from neural networks and regression analysis of paint thickness are compared. Andrea Maria Zanchettin [2] performed both experimental and simulation analysis on ABB IRB 140 for an extra degree of freedom. Here a method to enhance arbitrary repetitive resolution criteria is proposed while performing spray painting task and maximized the manipulability index.

Ijeoma W Muzan [3] experimented spray-painting process on ABB - IRB 1410. The flex pendant was manually taught, here 2 packages were utilized in this project for robot motion, the targets and paths of the alphabets are programmed using Robot studio and end effector was programmed by solid-works software. Also, RAPID GUI is utilized for interfacing robot and concluded to improve safety, reduce consumption of paint and enhance quality of paint. Yan Chen [4] developed a uniformity model for coating to optimize trajectory of robot in spray painting procedure. Based on thickness variation they evaluated uniform parabolic spray distribution and uniform robot motion. They obtained overlapping distance is a crucial factor which affects coating uniformity or thickness variation and work piece width, seed path position are other key factors. S. Luangkularb [5] proposed a model for positioning of spray gun position and predict the thickness of coating. They performed optimization for low paint consumption and standard film thickness by varying input parameters like spray pressure, nozzle size and spray time. Also, spray painting coefficient was introduced which was based on correlation between material consumption and coating thickness. Om Prakash Gujela [6] analysed on spray painting robot for acquiring joint angles and patches, end effector orientation and position. Inverse kinematics are utilized for joint angles and patches whereas forward kinematics for end
effector orientation and position. Utilized Denavit-Hartenberg (D-H) methods for solving forward and inverse kinematics and MATLAB is used for solving complex equations.

Yang Tang [7] generated a new algorithm for automated tool trajectory for spray-painting robots by free form surface of grid approximation. They utilized T-Bezier curves which are extracted from trigonometrical bases by varying distance between free-form surface and spray gun along the normal vector. Wei Chen [8] proposed spray-painting robot’s new trajectory by utilizing T-Bezier curves from T-Bezier basis. Also, for Bezier surface paint deposition rate function is specified. The given model is suitable having smooth trajectories and even for complex curved shape they obtained uniform speed for spray-painting process. Jun Wu [9] studied on 3 DOF planar parallel manipulator dynamic performance and workspace in spray painting equipment. The interference and vibration can be reduced by above manipulator by attaching the moving platform to the base and connecting with two kinematic chains. By utilizing virtual work principle, the inverse kinematics is formulated workspace is examined. R. Bhalamurugan [10] compared spray painting process to optimize control parameters for improving film adhesion, surface roughness and thickness variation with both robot ABB IRB 1410 and manual painting. Taguchi orthogonal array and grey relational analysis are utilized for robot painting and concluded speed, distance and distance are most influential parameters. Syeda Maria Khatoon Zaidi [11] developed an economic robot for painting operations in small industries with no health issues caused by painting process, easily replaceable and low cost. The robot is equipped with an arm of 4 degree of freedom and image processing techniques, also, placed on conveyor belt which has capability to paint complex shapes.

T. Thushar [12] investigated on performance of robot nano spray paint for optimizing thickness variation and quality of paint by varying input parameters like speed, pressure of paint and distance between spray gun and plate. A Minitab software was utilized to analyse the experimental data and generate the correlation between input and output parameters, and confirmation test was conducted to validate the experimental runs. Arif Santoso [13] presented an analysis of workpiece orientation for trajectory with 6 degree of freedom robot for spray painting application by utilizing blender open source software. They simulated and analysed 4 workpiece orientations which have 4 trajectories and 6 joint angles are iteratively changed on the software for inverse kinematics. The optimal trajectory is acquired from angular velocity and angular acceleration curves which are drawn by sampled time curves with respect to real time for six joint angles. Luca Geretti [14] studied on robot spray painter and analysed system parameters and dynamics of system. They utilized ARIADNE tool to observe spraying speed, quality. Binbin Zhang [15] proposed a method for spray painting of airplane wings by robot by dynamic feedforward control with time-varying dynamics and large workspace. Atlas method is utilized to design closed-loop feedback system control parameters. In industrial servo system only the velocity and acceleration feed forward controls are assigned. Meisam Vahabi [16] designed a spray-painting robot for coating roadside blocks by a two planar process i.e., a serial and a parallel manipulator with a prismatic joint which can easily paint two-dimensional paths. Here genetic algorithm was utilized to optimize the parallel manipulator joint position. Also, stroke angle and process space are optimized for varying height and lateral position of joint.

Artur I. Karimov [17] examined on tone rendition of paint robot which has capability for grayscale painting for monochrome coating consists of white and black acrylic paints. They generated an algorithm and mathematical model for paint mixing. Here the robot comprises of CNC machine with 3-DOF, syringe pump block, paint mixing device. K V Chidhambara [18] investigated on performance of dry film thickness by varying three input parameters like viscosity, paint flow and shaping air on Fanuc 250ib industrial robot. They performed statistical analysis i.e., taguchi L25 orthogonal array to optimize the output parameters also performed analysis of variance to understand the impact of each input parameter on output parameter. They generated a mathematical equation by utilizing multiple regression analysis which gives the correlation between input and output parameters.
3.2. Trajectory of Robot
Spray painting robots require higher speed and accuracy in production industries. So, path planning is a crucial thing in automobile industry for spray painting process. The trajectory planning includes degree of freedom (DOF), acceleration, velocity and position commands. The trajectory of the paint and painting time affects the thickness of paint. So, for uniform thickness of paint robot trajectory planning is very much needed, also increase life-time of paint. Pal Johan From [19] generated a new algorithm which is validated with both simulation and theoretical results. They proposed joint torques required for trajectory should be less than the conventional methods, which enhances uniformity of paint coating, throughout the entire trajectory constant speed is obtained. Wei Chen [20] proposed a new algorithm for spray painting robot in path planning. They concerned about deposition rate function of paint, and film thickness surface model is generated. In which with optimal film quantity and optimum time, optimal tool path with free-form surface is obtained. Yong Zeng [21] developed a new algorithm for trajectory of spray-painting robot. They generated a new model based on coating thickness for many times spray painting which concerns cycle and number of coating thickness obtained from offset distance between first spray gun trajectory of single time spray painting and subsequent spray gun trajectory. A uniform thickness of coating and optimize trajectory is obtained. S. Seriani [22] studied on robot spray painting of a greyscale image. They chosen large spray gun stroke, where the critical points or major shapes are obtained. Then goes with decreasing stroke diameters of spray gun, where even a minute detail is painted. At each point operational speed is calculated by least square method. This robot is more suitable for large paintings but the small or minute details are tough to be achieved.

Yan Chen [23] reviewed on simulation of trajectory planning and paint thickness of spray-painting robot. They compared computational fluid dynamics (CFD)-based method and explicit function-based method for thickness simulation of painting. They concluded that CFD based paint deposition method is utilized more in current scenario for simulation of thickness for spray painting robot. Xuhao Wang [24] studied on singularity of 7R 6-DOF painting robot which affects off-line programming, path planning and motion control of the robot. They considered non-spherical wrist of robot and compared spherical wrist 6R robot and non-spherical wrist of 7R robot, the orientation and position singularities are identified. Twist decomposition approach is utilized to overcome these singularities in both types. Kiyang Park [25] studied on painting robots in automotive industry which are incorporated with electrostatic rotating bell. They developed optimum coating path pitch for enhancing paint quality of automobiles. By utilizing deposition model for electrostatic rotating bell atomizer, the path pitch is optimized with uniform painting thickness and less cost. It is validated with experimental runs for optimal path pitch simulation. Liwen Guan [26] developed a new trajectory to optimize path of concave arc, convex arc and straight-line combinations between normal vectors for various angles. Also, distance between adjacent trajectories, spray height and paint velocity are determined to reduce spray paint thickness for any complex shape. Zilin Liu [27] examined on motion accuracy of robot by considering control parameters and workspace optimization. Initially a dynamic model was generated for dynamic load which works on dynamic evaluation index. Experimental runs are conducted to validate the method and dynamic index is utilized to ensure that the position is accurate for robot to optimize workspace.

3.3. Nano paint/Material
Generally, a nanomaterial or painting is classified as the thickness of the coating in nanoscale or on the other side particles that are dispersed into the matrix in the nanosized range or coatings having nanosized grains/phases, etc. Nanomaterials can be used in a wide range of applications including textile substrates for cell growth, textile implants, medical fabrics, bio-filtration materials, medical garments, and some other products of textile for medical systems and engineering systems like automobiles windshield and so on. Prabhu [28] analysed the surface roughness of Inconel 825 with a single wall Carbon Nano Tube (CNT) in the sinking EDM operations. By using the Design of
Experiment technique by modifying three parameters like pulse current, pulse duration, pulse voltage. With low pulse duration and high voltage and by utilizing single-wall CNT in the EDM machining process as dielectric fluid the better surface finish, morphology and reduced cracks can be achieved. Mathiazhagan [29] reviewed on nano fillers/particles, figments used and organic coating types for applications of coating. Protection from corrosion is the main application of nano coating which enhances some special features like physiochemical, chemical and physical properties. Also, concluded that improvement is required regarding human health safety.

Ahmed Al-Kattan [30] studied on material characteristics which are released from nano paint with a combination of nano SiO2 due to water exposure and weather conditions. After the 89 six-hour cycles of UV illumination and additional tests shows that most of the released form of nano paint is dissolved form of water of SiO2-NPs and remaining form was like a particulate and nanoparticulate form of Calcium Ca were detected. Prabhu [31] studied on AISI D3 tool steel material surface roughness in Grinding process of CNT mixed nanofluids for the dielectric. They utilized neural network analysis and fuzzy logic for predicting the surface roughness by varying different parameters like feed, speed, and depth of cut. Chi-Chi Lin [32] studied on biological resistance of paint materials with different resin types and composition. Suggested that for enhancing fungal resistance enriched acrylic resin percentage with high porosity materials have the ability of strongest fungal resistance. Ye [33] examined on particle size distribution and composition of materials in paint overspray. Different types of primers and nanomaterials were utilized and aerosol measuring techniques are applied. Concluded that Solvent-borne primers have a higher composition of nano-droplets with a particle size distribution of less than 1 µm. Soheil Jafari [34] studied on various engineering applications of CNT and concluded that CNT plays a vital role in automobile, food technology, and biomedical applications, and can also be used in recent technologies like wind turbines, actuator, sensors and solar panels.

Yuanyuan Zhang [35] investigated on single-walled CNT and primers with various proportions to diminish the hygroscopicity and surface gloss. Obtained high glass transition temperature, adhesion of hybrid films and hardness with single-walled CNT with 0.025% weight. Bir B. Bohara [36] fabricated a nano paint with a combination of lead magnesium niobite and titanate in less cost, energy and time with brushing method. It is utilized to fabricate high energy storage capacitors, piezoelectric devices for energy conversion and sensors. Hai-Long Yao [37] investigated different processing parameters like temperature, coating thickness, coating formation, particle composition, spray distance, and powder-structure. Concluded that ultrathin ceramic coating can be utilized for solar cells besides thick ceramic coating can be utilized for batteries and fuel cells. Elena Semenzin [38] proposed a methodology for the risk control of humans due to nanomaterials as they are hazardous to the environment and human health. But by modifying the composition, technologies utilized and controls the effect of nanomaterial can be reduced like basic carbon carbonate and nanoscale copper oxide. E. Kabeel [39] examined the solar system with pyramidal basin type performance that the absorber plate is coated with black paint which consists of TiO2 nanoparticles. When the system is submerged in the water the temperature of the absorber plate increases by 1.50°C than the conventional plate. As efficiency increased by 6.1% than the traditional system.

3.4. Heat Treatment
A. Simpson [40] studied on thermal performance and characteristics of paint. They compared the conventional coatings with dynamic coatings, the conventional coatings are normal polystyrene liner, wallpapers and emulsion paints. They obtained the thermal paint coatings with nano material have life time of several hundred years with energy savings of 0.4% to 2.9% based on type and thickness of coating.
4. Conclusion
From the literature survey a clear idea about the automated robot painting and the different factor affecting output quality of the paint coating are obtained. The literature explains how the industrial robot specifically IRB1410 can be used for painting application. Paint thickness variation can be predicted using computer program and simulation. Using the robots along with paint algorithm will reduce the joint torques needed to follow a specific end effector trajectory. Software like Solid work and Robot Studio can be used to model and simulate paint coating. The fuzzy logic, neural network and regression model can be used to model a knowledge and used for prediction of paint quality. The distance between spray gun and substrate should be optimised for thin film thickness and adhesion. From this review it is inferred that there is scope to use ABB IRB1410 robot for painting purpose and distance between spray gun and substrate should be optimised for thin film thickness and adhesion.

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