Design and Implementation of Painting and Replacement Automation Robot System in Spindle Line for Smart Manufacturing

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Abstract: In the process of painting the surface of injection products, the spray trajectory and speed are very important and have a very important effect on productivity and quality. However, since it is very difficult to standardize and quantify each product, it was difficult to apply automation to the painting process, so there were many cases where people directly operated it. Recently, with the development of robot technology, many manufacturing processes performed by humans are being replaced. To automate painting in the spindle line of the painting process, we design Painting and Replacement Automation Robot System in Spindle Line. By implementing it in an actual production line, we have greatly improved productivity and reduced paint replacement time.

Key-Words: Smart Factory, Injection Molding, Painting, Articulated Robot, Spindle Line, Automation, Smart Manufacturing.

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1 Introduction

A smart factory is an intelligent factory that applies ICT technology to all production processes, from product planning to sales, to maximize operational efficiencies, such as productivity improvement, quality improvement, and cost reduction, and to produce customized products. Quality is a very important factor in the manufacturing industry and has a significant impact on the growth of companies and securing market competitiveness, [1]. In the manufacturing industry, the painting process is a very important part of the manufacturing process, and especially in the plastic injection industry, the quality of the product is very closely related to the spraying technology in the painting process. The painting process is a typical 3D environment, and since most of the paints used in the process are toxic products, it is fatal to the human body, and the spraying and processing of paints depend on the skilled technicians of technicians, so it is impossible to replace human resources and highly dependent on technology. To solve such a problem, a painting system using a robot is being actively researched. However, in the case of products of complex shape or small size, it is difficult to operate using a painting robot, and the composition of the robot environment according to product changes such as product color, spraying speed, and trajectory is inefficient in the painting process using robot automation, resulting in time and inefficiency. It causes many constraints.

The structure of the paper is as follows. Section 2 discusses related research, the theoretical background before introducing the system proposed in this paper. Section 3 introduces the design of Painting and Replacement Automation Robot System in Spindle Line proposed in this paper. Section 4, Experiments and Evaluation, explains the experimental environment, experimental results, and performance evaluation of the proposed system. Finally, in the conclusion of Section 5, the results of the study and future research are described. In this paper, it is possible to implement an efficient production environment by deriving the spraying trajectory, controlling the amount of paint, and applying Auto Color Change to realize optimal painting quality using a robot. Through the proposed system, production speed and painting automation at the level required in actual manufacturing sites are possible, and the research results will be used as important data to improve process efficiency and product quality.

2 Related Work

In this chapter, before introducing the proposed system, the theoretical background and related research are explained, and optimization and automation for system design are described. Paint spray trajectory modeling is an important field that is attracting attention in the industry, and various models are being developed and used. Since the 1990s, the process of trajectory planning, [2] and optimization problems have been studied for uniform paint spraying based on CAD models [3]. The method of deriving the trajectory of a product through an intersecting plane on the product surface is described in [4]. In the method proposed in [5], a method of generating a spray trajectory on a 2D surface by calculating a curve with minimized curvature was studied. A programming-based approach is described in [6], and [7] conducted a study to maintain an even surface while minimizing the waste of paint.

2.1 Smart Manufacturing

Smart manufacturing refers to digitalization, standardization, and integration for an efficient manufacturing environment by combining various technologies such as the Internet of Things (IoT), robot, automation, big data, cloud, and edge computing, [8]. The concept of smart manufacturing has been defined by several organizations in the US, such as the Department of Energy (DoE) and the National Institute of Standards and Technology (NIST), [9], [10], [11]. In general, Intelligent Manufacturing is sometimes used without being distinguished from Smart Manufacturing. The technology and essential elements of smart manufacturing were studied to explain the difference between smart manufacturing and intelligent manufacturing, [9], [12], [13].

Intelligent Manufacturing refers to a manufacturing environment that is more closely related to technologies such as Artificial Intelligent and Machine Learning and enables active operation. On the other hand, there is a difference between Smart Manufacturing and Intelligent Manufacturing in that Smart Manufacturing focuses on data-based operational efficiency, [14], [15].

We tried to implement Smart Manufacturing by computerizing and standardizing the data that exists as know-how in the manufacturing domain and then constructing a system that controls using robots.

2.2 Optimization

Deriving the optimal spray trajectory in the painting process is very important. Because the coating thickness of a product has a very important effect on quality, traditional manual methods had to rely on the know-how of technicians. In this chapter, we derive the optimal spraying trajectory for the realization of the painting robot system using robots to produce high-quality products. To derive the spray trajectory, various variables such as the position, direction, andspeed of the spray gun must be considered. To optimize the spray gun according to the product, the product is 3D scanned to derive x and y values. The production speed and distance between products are derived to optimize the painting process. The algorithm for deriving the spray trajectory is described below, [16].

Given a paint gun profile, the paint thickness on a fiat patch is related to the paint gun velocity and the overlap distance.

$$\bar{q}(x, d, v) = \frac{1}{v}\rho(x, d) \quad (1)$$

Moreover, the paint thickness is inversely proportional to the paint gun velocity. This means: where
$q^{-}(x, d, v)$ is the paint thickness on a plane; x the distance to the gun center; d the overlap distance; v the
gun velocity: ρ is a function of x and d To find an optimal velocity v and overlap distance d the mean square error of the thickness p_d deviation from the required thickness must be minimized, i.e.,

$$\min_{d \in [0, R], v} E_1(d, v) = \int_0^{2R-d} \left(q_d - \bar{q}(x, d, v)\right)^2 dx \quad (2)$$

The maximum paint thickness and minimal paint thickness have to be optimized too because they will determine the paint thickness deviation from the average paint thickness.

$$\min_{d \in [0, R], v} E_2(d, v) = (q_{\max} - q_d)^2 + (q_d - q_{\min})^2 \quad (3)$$

From equations (2) and (3), we have:

$$\min_{d \in [0, R], v} E(d, v) = \frac{1}{2R-d} E_1(d, v) + E_2(d_1 v) \quad (4)$$

The minimization of E(d,v) is only related to the overlap distance d.

2.3 Automation

Auto spray painting can atomize paint by using compressed air as an energy source, and it is possible to paint by adjusting the viscosity of paint in various patterns and a wide range.

When using an auto spray gun, the coating should be done considering the number of overlaps according to the shape of the pattern. In general, circular patterns should be painted with 1/2 overlap, oval patterns with 1/3 overlap, and rectangular patterns with 1/4 overlap. In addition, the viscosity of the paint generally uses 13 ~ 16 sec in Primer Coat, 20 ~ 30 sec in Top Coat. Since the viscosity of the paint is very sensitive to temperature/humidity, the viscosity of the paint must be kept constant through constant temperature and humidity.

Paint is filled in the gun body, and the filled paint is operated by a trigger signal from the robot to make a pattern of a certain size and color the surface to be painted.

When the air pushing the needle is discharged through the cylinder by the trigger signal, the needle and saddle are brought into close contact with each other by the pressure at the rear end of the needle, and the spray is sprayed.

The 3-Way color change is a device for controlling the flow of paint in two directions (Inlet, Outlet, Return). It is operated by a sol valve and classified as N.C/N.O type. If the paint is stagnant for a long time, mottling occurs due to hardening and pigment precipitation. In order to prevent hardening and mottling due to pigment precipitation, It is necessary to maintain the fluidity of the paint through continuous circulation or discharge, [17].

3 Painting and Replacement Automation Robot System in Spindle Line

In the manufacturing industry, the painting process is a very important part of the manufacturing process, and especially in the plastic injection industry, the quality of the product is very closely related to the spraying technology in the painting process.

A general cosmetic case painting process consists of 12 steps, and the current status of the painting process is as follows. Fig 1 is an introduction to the painting process.

Fig. 1: Painting Process for Cosmetic Case

Recently, a painting system using a robot is being actively researched for the automation of sophisticated spraying technology. However, in the case of products of complex shapes or small sizes, it is difficult to optimize color, spraying speed, and trajectory with each product change.

In this paper, we propose a painting process automation system using a robot that derives the spraying trajectory, controls the amount of paint, appliesauto spray and auto color change, and meets the production speed required by the manufacturing site to achieve optimal painting quality.

Table 1 describes the specifications of the robot and the main parts used in the system proposed in this paper.

Table 1. Specifications of Main Parts

Category	**EA**	**Manufacturing Company**	**Spec.**
Robot	1	HYUNDAI	Degree of Freedom: 6
Auto Spary Gun	8	DURR	Ecogun AS AUOT Mini FS
Color Change Cartridge	8	DURR	10port
Gear Pump System	5	DURR	3cc/1r
Electric Sol Valve	16	SMC	-

Fig. 2 shows the painting process automation robot concept applied to the system proposed in this paper. For the coating of fast-moving products on the Spindle Line, 8 spray guns and color change cartridges capable of driving each x and y-axis can realize optimal product coating. It moves quickly from the top to the top to realize vertical painting, derives the optimal spraying trajectory based on 3D, and implements an automation process that produces quality products.

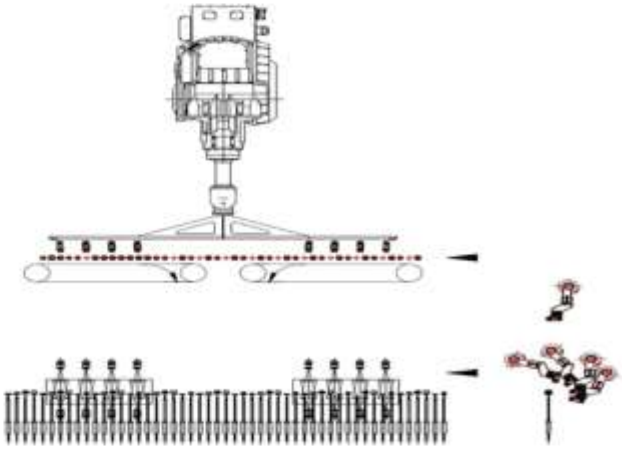

Fig. 2: Design Concept of Painting Process Automation Robot

Auto spray gun and 3-Way color change move up and down using minimum paint through spray trajectories optimized for each product, apply the product to the surface, and apply overlapping paint to maintain a constant coating thickness of the product, constant temperature, and humidity It realizes painting automation by maintaining the best paint condition in an enclosed space. When changing the product, the machine replaces the color change and cartridge cleaning, which were manually performed by people, and the replacement and cleaning work that previously took 2 hours can be reduced to less than 15 minutes. Fig. 3 is an image showing the Auto spray gun and 3-Way color change cartridge.

Fig. 3: Auto Spray Gun & 3-Way Color Change Cartridge

4 Experiment & Evaluation

To verify and apply the system effect proposed in this paper, an experiment was conducted with domestic manufacturing companies. The company produces cosmetic cases. Because the cosmetic cases have complex shape and small size, it has been painted only by hand. We implemented and tested the painting process automation system using robots by constructing robots in the cosmetic case painting line.

4.1 Experience Environment

This company has a Spindle Line(86m) for painting the surface of cosmetic cases. Fig. 4 shows examples of items actually produced by this company.

Fig. 4: Cosmetic Case Image before/after Painting

Also, we had to consider the production conditions.

The production conditions are as follows.

- Existing spraying speed: 3m/min
- Product thickness: 75mm
- Production: 159.6ea/min
- Existing color replacement time: 20min

The experiment contrasted and compared with the status of the painting process described above, along with the daily production volume and process defect rate of products recorded through daily reports before the construction of the painting robot, and Fig. 5 shows the picture after the construction of the painting robot.

Fig. 5: Painting Process after Constructing the Robot System

4.2 Experiment Result

To verify and apply the system effect proposed in this paper, an experiment was conducted with domestic manufacturing companies. Before building the painting robot, the daily production of products was 58,000 pieces/day, and the process defect rate was 3.2%. After the painting robot was built, the daily production number of products was 67,200 pieces/day, and the process defect rate was 2.0%, respectively 15.9%, and 37.5% respectively. showed effect. Table 2 shows the performance index before and after the painting robot.

Table 2. KPI before/after Constructing Robot System

Key Performance Indicator	Before	After	provement rate (%)
Production (ea/day)	58,000	67,200	15.9
Defective rate (%)	3.2	2.0	37.5

5 Conclusion

In this paper, we proposed Painting and Replacement Automation Robot System in Spindle Line using an articulated robot. For the experiment, we successfully implemented a painting robot system in the cosmetic case painting process. In order to realize the optimal painting quality using robots, the spraying trajectory was optimized, the amount of paint was controlled and Auto Color Change was applied to realize an efficient production environment.

Through the proposed system, production speed and painting automation at the level required in actual manufacturing sites are possible, and the research results will be used as important data to improve process efficiency and product quality. Robots that perform human-body driving functions are expected to be needed in various industrial fields in the future. We plan to research applications that can disseminate and expand the technology in various areas such as smart factories, smart cities, and smart farms that require the role of robots.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.