Investigating and improving Boeing aircraft composite panel industrial painting issues by designing smart robotic precision painting system

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Abstract. Aerospace Composites Malaysia (ACM) Sdn Bhd produces one of the aircraft components, which is an aircraft composite panel. Currently, the painting of the composite aircraft panel is manually conducted by the high skilled human operator. However, there are several issues of manual painting, which are the precision of the thickness specifications, uneven spray, dust-free, microbubble, colour appearance, and contour of the aircraft composite panel. Consequently, these issues contribute to the aircraft aerodynamic performances, productivity, and index time of the aircraft composite panel's production. Thus, the main objectives are to investigate the human painting mimicking robot incorporated with the existing painting environment. The proposed environment becomes smart precision painting systems. In conclusion, the proposed prototype will overcome the quality issue of aircraft composite panel painting faced by Boeing worldwide aircraft industries. Furthermore, the proposed prototype will increase productivity and contribute to the maintaining of the aircraft's aerodynamic performance.

1. Introduction

Aerospace manufactures is one of the leading manufacturing sectors in the current world which produces many aircraft parts and one of them is aircraft composite panel. At the present, the painting of the aircraft composite panel is done manually by a highly trained human operator. A highly qualified and
experienced human operator is needed to produce a high-quality painting. A long period of learning time is needed to become a highly skilled human operator, but some people can still create high-quality paintings. Furthermore, once they leave, ACM would have difficulty training a new human painter. A human-painting-impersonating robot is suggested to be integrated into the actual painting system as a solution to these problems.

The suggested system evolves into intelligent precision painting systems. Three objectives achieve the goal: to build a robot workspace with less participation from the human operator. The second goal is to integrate the preferred human painting action into the movement of the robotic arm holding the spray gun. The third goal is to create accurate robotic spray systems for achieving consistent spray patent and length, which will remove mitigating factors, including uneven spray, microbubbles, and dust accumulation. Eventually, the proposed invention would address the consistency problem of aircraft composite panel painting that has affected global aircraft industries. Furthermore, the proposed invention would boost efficiency while also helping to maintain the aircraft’s aerodynamic stability.

2. Literature review

There is numerous robotics in the market, which perform a task such as painting aircraft. However, the challenges arise when some parts cannot be scanned or painted by robots as it lacks the "human-touch" [2]. The robots may be programmed to scan and paint a surface, but they may not deliver that task at a certain angle and geometry. A study has been conducted in [3] demonstrated that robots could be programmed to spray on unknown surfaces. Using the project Flex Paint approach, they divided it into four steps which are laser triangulation sensing, geometric feature detection, tool path planning, and collision-free executable robot program. They can demonstrate robot spray painting on unknown surfaces. Instead of using CAD data, their method uses range sensor data to obtain robotic paint paths and automatically generate feasible, complete executable robot programs. Their approach uses sensing cells in front of painting cells to acquire geometry [4, 5].

The biggest advantage of automation is that it saves power, energy, and materials and improves quality, precision, and accuracy [6]. Savings achieved through paint thickness tolerance control and trigger accuracy will relate directly to many other savings such as exhaust (Tolerance control/trigger accuracy directly reduces stack volatile organic compounds (VOC) volumes), overspray (Reductions go directly to less filter usage or chemical usage with water wash booth) and reduced rework (Problems such as sags and modelling should be reduced), reduced scrap (Less material to landfill) [7]. Other than that, the usage of paint robots has always been environmentally friendly [8]. Some common problems during manual painting on aircraft surfaces are poor adhesion, blushing, sags and runs, pinholes, orange peel, fisheyes, sanding scratches, and wrinkling and spray dust [1]. Moreover, aircraft parts painting incorrectly can also have dangerous effects on their performance; thus, proper painting techniques and specialized materials and equipment to complete an aircraft paint job are required. Apart from its billions of USD market value, robots give an abundance of advantages such as increased cost reduction, increase in efficiency, quality and reliability, and others [9].

Currently, the painting of the aircraft composite panel is manually conducted by the high skilled human operator. Only high skilled and experienced operators can perform the task to produce a high quality of the painting. However, the process of manual painting consumes too much time. Furthermore, the presence of a human in the robot workspace will bring contaminants such as dust to the workpiece. Several issues occurred from the manual painting: the precision of the thickness specifications, uneven spray, dust-free, microbubble, colour appearance, and contour of aircraft composites panel.

Specifically, some of the common problems that may occur during manual painting on aircraft surfaces are poor adhesion, blushing, sags and runs, pinholes, orange peel, fisheyes, sanding scratches wrinkling, and spray dust. Consequently, these issues will contribute to the aircraft aerodynamic performance. Moreover, aircraft parts painting inaccurately can also have dangerous effects on its performance thus, proper painting techniques and specialized materials and equipment to complete an aircraft paint job are required. Also, the manual painting process consumes much more paint which increases waste and expenditure. Thus, an automated painting system could increase the productivity
and index time of aircraft composite production. The proposed prototype will overcome the quality issue of aircraft composite panel painting faced by Boeing worldwide aircraft industries.

3. Methodology
The methodology consists of three main parts to be included in this research. This includes developing a suitable working environment or workspace for the robotic spray gun system, incorporation of human mimicking robot spray painting and precise painting algorithm into the robotic spray painting system, and lastly the prototype testing, monitoring, and validation that will ensure the usability and efficiency of the robotic spray painting system. Figure 1 shows the sketch of the spray booth.

3.1. Phase 1
For the first part, developing a working environment or workspace for the robotic spray-painting system is designed and executed. For this phase, the workspace is designed to isolate the spray-painting robotic system from being exposed to the external environment, eliminating contaminants that could lead to dust accumulation, uneven spray, micro bubble formation, and contour. This design of workspace or booth will enclose the spray-painting robotic system from being exposed whilst keeping the paint itself from being spread outside the environment resulting in polluting. The required volumetric flow rate for the spray booth and the reference list of cart dimensions for painting purpose is listed in Table 1. The cart is used to place the panel for the painting process.

Figure 1. Spray booth sketch
Table 1. Required volumetric flow rate for spray booth and required painting criteria for cart.

| Parts         | No | Properties                  | Value                  |
|---------------|----|-----------------------------|------------------------|
| Painting room | 1  | Requirement spray chamber   | 20.38 m/min            |
|               | 2  | Chamber size                | 59.16 m²               |
|               | 3  | Volume flow rate            | 1803.197 m³/min        |
| Cart          | 1  | Cart dimension              | 2.7m × 0.84m           |
|               | 2  | Spray pattern width         | 0.300m                 |
|               | 3  | Overlap                     | 50% (150mm)            |
|               | 4  | Height nozzle to panel      | 0.0254m                |
|               | 5  | Spray volume setting        | 40cc/min               |

3.2. Phase 2
Next, incorporating human mimicking robots and precision system painting algorithms into the robotic spray is developed. This phase is initiated by developing a reliable mechanical system for consistent 6+2 movements in the painting system with 6+2 axis movements gantry spray painting gun system while fulfilling the desired design of a human mimicking robot precision system. These criteria are taken into consideration which includes a reliable control system for eight motors synchronize movement, reliable spray gun control (standard for consistent spray-painting mechanism and a reliable paint feeding system to avoid microbubble formation and uneven paint thickness. These are taken into consideration to ensure the best spray-painting mechanism ensuring a consistent or even better-finished workpiece. In Figure 2, the spray-painting robot system is equipped with a manipulator, DX200 robot controller, manipulator cables, and programming pendant.

![Figure 2. Overview of spray-painting robot](image)

3.3. Phase 3
The phase in which the testing, monitoring, and validation are performed onto the completed design of a human mimicking robot precision painting system. This phase is necessary to ensure the design is
robust, efficient, environmentally friendly, and it can complete the task as desired by the user with minimal human interaction.

4. Result and discussions

As seen in Figures 3, 4, and 5, the robotic spray-painting system has been modelled and tested out in a real working environment inside a workspace to compare its performances when working on a workpiece compared to a workpiece sprayed by an operator. For manual spray, the total paint volume recorded for one panel is five litres per five layers. In the new spray-painting robot system, the travelling distance for spray direction of the X-axis and Y-axis is 30.24m for both, respectively. An amount of...
11.2 times spray direction is recorded for X-axis spray direction and 18 times for Y-axis spray direction. Therefore, the total travelling distance for the five layers is approximately 151.2m. Table 2 shows the comparison between the systems.

**Table 2.** Comparison between robotic spray-painting system and manual painting.

| No | Calculation for manual painting | Calculation for robotic spray-painting system | Estimate improvement |
|----|---------------------------------|-----------------------------------------------|----------------------|
| 1  | Total spraying time per zone (5 layers)=270 minutes | Total spraying time per zone (5 layers)=23 minutes | 91.48% (±5%) |
| 2  | $V = \frac{270 \text{ minutes} \times 40 \text{cc/min}}{10.8 \text{ litres}}$ | $V = \frac{23 \text{ minutes} \times 40 \text{cc/min}}{0.92 \text{ litres}}$ | 91.48% (±5%) |
| 3  | Total paint volume at four zones=432.0 litres | Total paint volume at four zones=3.68 litres | 99.15% (±5%) |

With the new spray-painting robot system, the total paint volume recorded has been reduced to 3.68 litres from 432.0 litres. Therefore, the results have shown that the machine can complete a workpiece in only 23 minutes, while when compared to the workpiece being done by an operator, it took at least 4.5 hours to complete it. The quality of the painted panel is much better, and all the problems arise, such as poor adhesion, blushing, sags and runs, pinholes, orange peel, fisheyes, sanding scratches, wrinkling, and spray dust during manual painting on the surfaces of aircraft has been solved.

5. Conclusion

In conclusion, the design of a working environment with a precise spray gun robotic arm with a spray gun mimics high skilled human painting behaviour. It can achieve a constant spray mechanism that will eliminate contributing factors such as uneven spray and microbubble and dust accumulation can complete. This shows a huge difference in the time spent on a workpiece, especially in the production line. Time enhancement has been recorded, which reduce more than 11.7 times compared to manual painting. Thus, time can be saved, and productivity can be raised. The amount of waste and paint expenditure can be saved on average of 95.32% (±5%). This, however, needs to be verified accordingly to each of the workpieces for us to validate that the finished workpiece is of the best and consistent quality and less time-consuming. Therefore, the overall painting efficiency is improved by using the human mimicking robot and improving the aerodynamic solutions in Boeing aircraft.

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