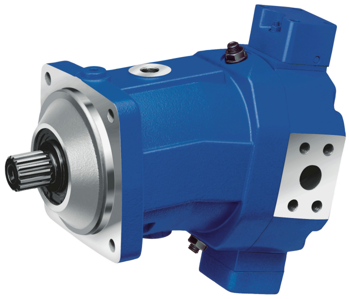
SprAIpaint

Motius GmbH
December 18, 2025 10:46 (ed3285d)

SprAIpaint

Status Quo

Our customer produces & paints industrial automation equipment, using manual spray-painting with 4 painters per shift. The current process involves manually painting a product that feature complex geometries with ribs and undercuts, making uniform coating application challenging.



Products are hung at different mounting points depending on their center of gravity, and single-stage paint is applied over pre-primed surfaces using a paint gun.

Goal

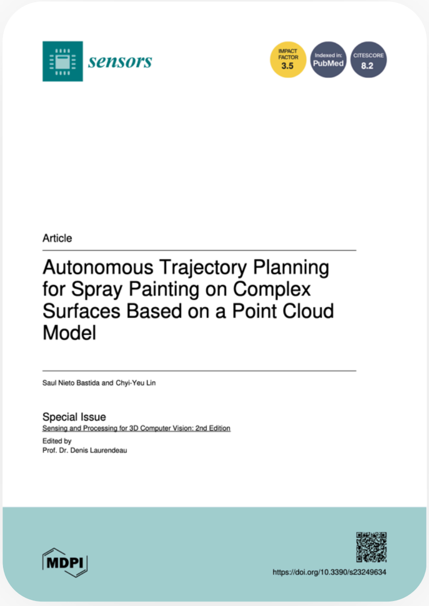
Develop an automated painting cell that can deal with complex geometries, and high variance in product configurations.

- [x] Scan part geometries, because CAD data is not available for all product variants
- [x] Automatically create painting paths using a "classic" algorithm, or a hybrid AI-based approach
- [x] Ensure full surface coverage on complex geometries, while avoiding paint runs and overpainting
- [x] Handle high variance in product configurations

State of the Art

Current research and existing solutions include:

- **Fraunhofer Institute**: Previously worked on similar automation but struggled with complex geometries (reference project)
- **Academic Research**: A lot of research exists on path planning, modeling paint application, and simulating robotic painting
- **Commercial Solutions**: Most industrial robot OEMs offer automated painting solutions, usually for parts with less variance and a focus on high-volume production


sensors

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Article

Autonomous Trajectory Planning for Spray Painting on Complex Surfaces Based on a Point Cloud Model

Saul Nieto Bastida and Chyi-Yeu Lin

Special Issue

Sensing and Processing for 3D Computer Vision: 2nd Edition

Edited by

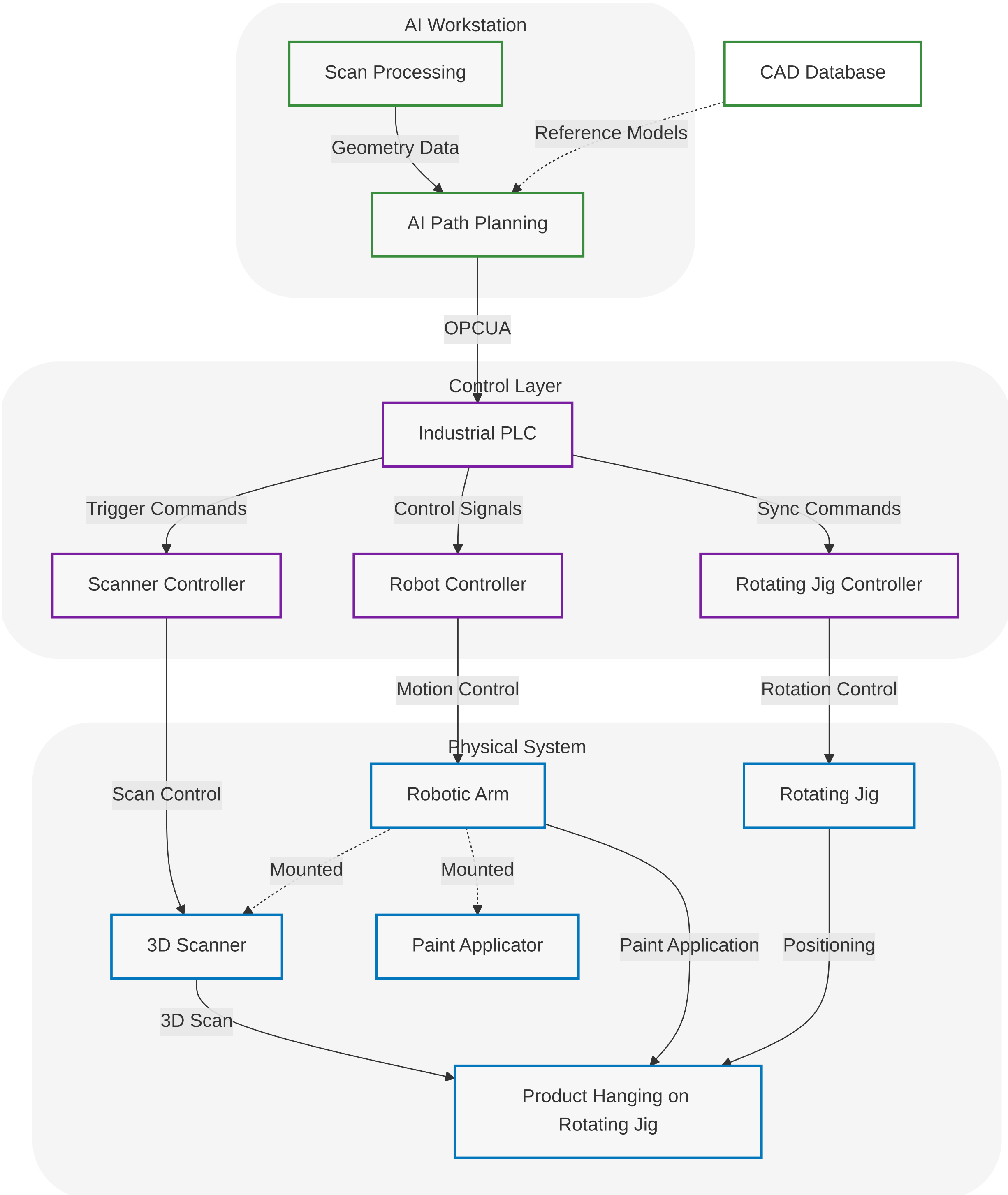
Prof. Dr. Denis Laurendeau

MDPI

https://doi.org/10.3390/s23249634

MDPI paper on path planning for spray-painting automation

Proposed Solution



3D Scanner

Solution	Accuracy	Speed	Cost	Integration Complexity	Constraints
MetraSCAN 3D (Robotic)	High	Fast	High (€100k+)	Low	Scan happens in one central location
Stereo Camera + VisionLib	Medium	Very Fast	Low (€1k-3k)	Medium	Requires CAD data of all variants
EinScan Pro HD (Handheld)	Medium	Medium	Medium (€15k-25k)	High	Process stability & speed may be lower than the other alternatives

Industrial-grade scanners like the MetraSCAN 3D provide high precision and speed, ideal for complex geometries, but with a higher upfront cost.

Combining a stereo camera with a tool such as VisionLib offer a cost-effective solution if CAD data can be used for part positioning and path planning. **Since CAD data is not available for all product variants, this approach is unlikely to work.**

Handheld scanners like the EinScan Pro are cheaper, offer good precision, but are more complex to integrate into an automated system.

Any vision system in a painting application needs to be protected from paint particles, for example with air curtains, shutters, or physical separation of scanning & paint application.

Recommendation

Due to a lack of CAD data for all product variants, the recommended approach is to use a high-precision scanner like the EinScan or MetraSCAN 3D. The exact variant, and automation strategy will depend on integration constraints in the paint booth.

For example, a more expensive robotic scanner only makes sense if the scan happens before the ceiling-mounted convery system diverges into separate material flows.

Mounting the scanner system on the paint applicator could work in each paint booth, but scanning products with no fixed frame of reference (MetraSCAN 3D) or CAD data (VisionLib) could impact process stability.

Industrial Robot & Automation

As a first step, we would recommend using an existing industrial robot with a spray-painting attachment, and a retro-fitted scanner. A subset of products reach this robot painting station, suspended from a ceiling-mounted conveyor system.

The products need to be mounted in a rotating jig or on a turntable, to allow the robot to access all surfaces.

Alternatively, the robot itself could move on a linear axis. Combined with the movement of the conveyor, the robot could also reach all surfaces of the products in two steps.

Additionally, the robot needs to be integrated into the path planning with a PLC, and there needs to be a safety concept for automated operation.

Recommendation

For the robotic arm & associated parts, we would recommend using an existing supplier, with existing service agreements. Most suppliers offer robots for automated painting applications.

Path Planning

The path planning algorithm can be implemented using a combination of geometric analysis and AI-based techniques.

Initially, the algorithm could follow what workers do, by segmenting the part geometry into different surface types and applying appropriate painting strategies for each type.

Geometry Type	Path Strategy
Flat surfaces	Raster path (zig-zag) perpendicular to faces
Cylindrical finned body	Helical or axial sweep with product rotation
Edges and transitions	Blend paths between surface types

An AI-based path planning algorithm could be trained on a synthetic dataset of part geometries and a simplified physics model of the paint application, using reinforcement learning to optimize for uniform coverage and minimal overspray.

Even further down the line, new visual foundational models like V-JEPA 2 could simplify the approach by directly predicting optimal painting paths from a 3D camera feed.

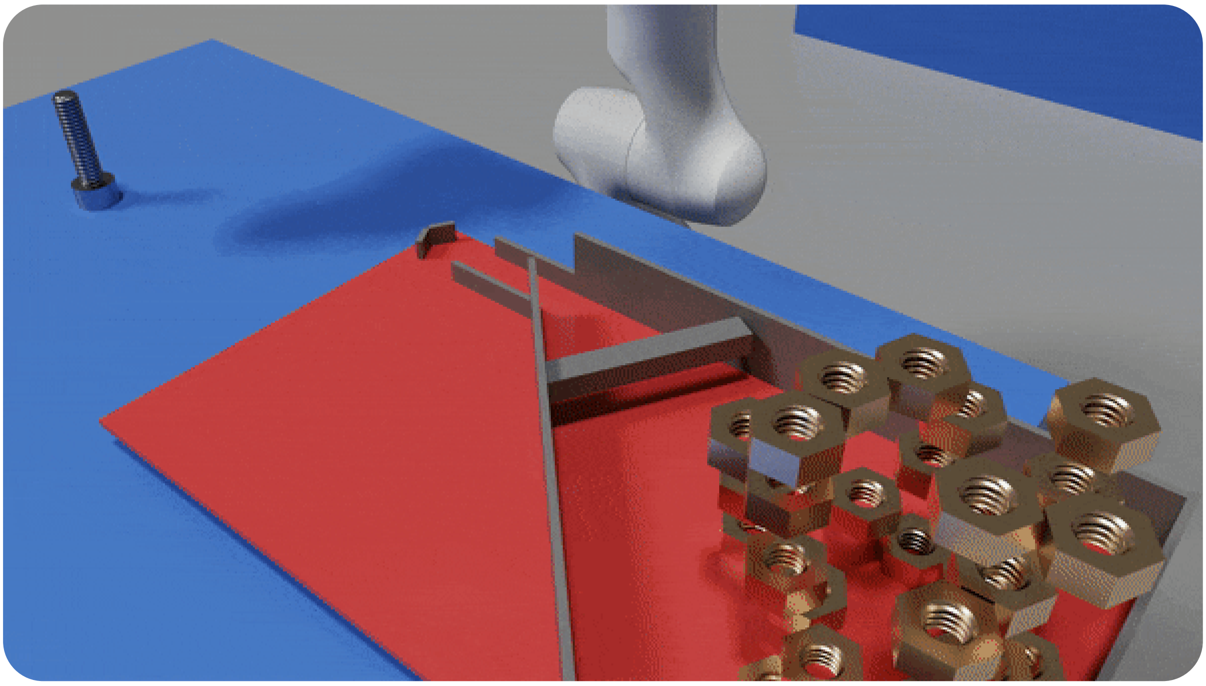
Recommendation

We propose segmenting the part geometry into a small number of geometry types and applying predefined painting strategies for each type. The strategies are derived from manual painting techniques.

The architecture of SprAIpaint should enable AI-based systems in the future, since the pace of development suggests that future versions of V-JEPA or similar models will be able to handle complex robotic tasks.

Simulation, Training, and Synthetic Data

Developing a classic algorithm, or training an AI-based path planning algorithm requires a simulation environment, a physical model of the paint application, and a dataset of part geometries.



IsaacSim simulation of a Franka robotic arm learning to pick a bolt and screw it onto a bolt using reinforcement learning

Recommendation

To validate the recommended approaches, we propose building a simulation environment first, using NVIDIA Isaac Sim or similar.

Approach

We propose an iterative approach, under the assumption that the manual painting process can be automated with a combination of simulation, classic path planning algorithms, and AI-based image segmentation.

❶ Virtual Environment & Path Planning

Build foundation for algorithm development and testing without hardware.

- Interview two expert painters, as well as automation experts with an automotive background from Motius' network
- Create high-fidelity simulation using NVIDIA Isaac Sim or similar
- Import representative geometries with all typical geometry types from the CAD database
- Implement a simple, cone-based paint flow simulation and surface coverage calculation

- Develop geometry-based algorithm using surface segmentation approach
- Validate coverage quality and cycle times in simulation
    - Physics based vision simulation using Isaac Sim sensors
    - Realistic robotic arm control in ROS2 and MoveIt

Deliverables: Working simulation environment, initial path planning algorithm, coverage metrics

❷ Physical Prototype

Prove concept with real hardware in controlled environment.

- Assemble test cell with industrial robot, turntable, and 3D scanner
- Implement 3D scanning stage and post-processing of the point cloud data
- Port parts of the ROS2-based control into the robot PLC
- Iteratively improve path planning based on real-world results

Deliverables: Working lab prototype, validated path planning algorithms, initial safety protocols

❸ Pilot Line Integration

Goal: Deploy industrial-grade system in the production environment.

- Interface with existing manufacturing execution systems
- Train personnel for system operation and maintenance
- Fine-tune performance

Deliverables: Pilot production line, trained operators, validated quality metrics

Scope of the Project

For the first project, our team will set up a virtual environment with physics-based simulation of the sensor and painting process. In this environment, the team will develop a path planning algorithm that gets executed on a simulated industrial robot.

The goal is to show that such a path planning algorithm can be developed in a short time period, and that it can recreate the manual painting process by segmenting products into different geometries and painting them accordingly.

ROI Analysis

The following analysis is meant to provide a rough estimate of the ROI for automating the painting process. The costs for an automated system are based on our experience in similar robotics & AI projects.

> **Note**
>
> Almost all parameters can be adjusted in the form below, the ROI results update automatically.

Current Manual Process Costs

Number of painters:

4 × 3 shifts × € 50000 /year

Labor: €600,000

Base annual paint cost:

€ 100000 + 15 % waste

Paint Cost: €115,000

Daily production:

3000 products/day × 0.5 % × €
30 /h × 1h rework

Rework: €112,500

Total Annual Operating Cost: €827,500

Automated System Investment

Total hardware cost (for all stations):

€ 200000

Software development:

€ 400000

Installation & commissioning:

€ 100000

Total Initial Investment: €700,000

Automated System Operating Costs

Maintenance & support:

€ 60000 /year

Reduced paint waste:

€ 0 /year

Operator supervision:

€ 135000 /year

Total Annual Operating Cost: €195,000

ROI Calculation Results

Annual Savings: €632,500

Payback Period:1.1 years

5-Year NPV (8%): €1,825,389

ROI after 5 years:361%