Robotic Paint Quality Control: Coordinated Mobile Manipulator and Color Verification

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Abstract

This study examines a mobile-robot paint inspection system using a six-axis manipulator fitted with a rectangular LED array and camera for in-line automotive body color verification. Base and arm motions are synchronized by a unified planner to maintain sensor orientation, stand-off distance, and perpendicular viewing across complex contours. Acquired images undergo lens correction, illumination-invariant preprocessing, and color-histogram analysis. Quality control passes when histogram similarity to reference samples meets a predefined threshold. Simulation on vehicle shell models under varied lighting showed uniform, red-dominant histograms across doors, pillars, and recessed panels, confirming glare-free, repeatable measurements and reliable detection of subtle deviations without impacting throughput. This approach provides an automated alternative to fixed and handheld systems, enhancing coverage and consistency in automotive paint quality assurance.

Keywords: Image processing, computer vision, mobile robot, robot manipulator, light illumination.

Ⅰ. Introduction

Automotive plants usually check paint color with either stationary vision cells or handheld spectrophotometers positioned at the end of the paint line. These setups place fixed LED or fluorescent arrays above the car while cameras or colorimeters capture surface reflectance and compare it with reference swatches[1]. Such installations work well on broad, flat body panels and have become routine quality control stations that keep pace with production throughput. Recent upgrades multispectral sensors, faster line scan cameras, and inline colorimeters have trimmed cycle times, yet the core workflow remains unchanged: a rigid fixture inspects a precisely indexed vehicle [2].

Rigid or handheld solutions falter when the surface is curved, recessed, or highly glossy. Fixed rigs cannot tilt to suppress specular glare, and handheld probes vary in distance and angle from one operator to the next, as seen in Fig.1. Factory lighting, airborne overspray, and dust introduce uneven illumination that shifts measured color values [3], forcing generous tolerances or expensive rework.

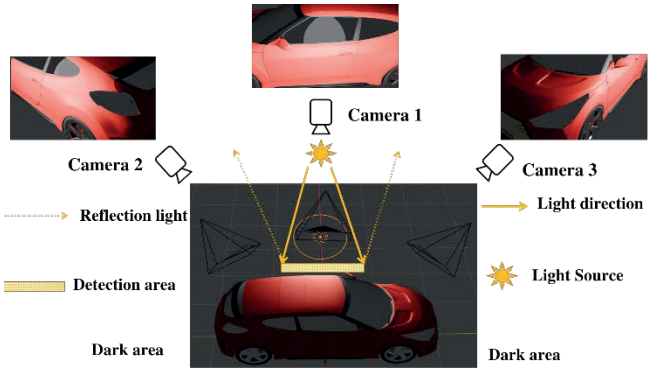

Fig.1 Uneven illumination

In this work, a mobile robotic platform that addresses these gaps by coupling a six axis manipulator with a collocated high resolution camera and LED light source. The robot autonomously navigates around the vehicle, positioning the camera light module perpendicular to each inspection point while holding a constant standoff distance. Real time visual feedback fine tunes pose and exposure to eliminate glare and maintain uniform illumination, regardless of surface shape. This integrated approach delivers repeatable, spectrally accurate color measurements across the entire body, removes operator bias, and extends automated paint quality control to areas that conventional systems cannot reliably inspect [4].

Ⅱ. Proposed System

A self guided mobile robot first circumnavigates the parked vehicle, pausing at pre programmed viewpoints to capture high resolution images of every painted panel, as seen in Fig.2. A rectangular LEDs mounted near the camera guarantees even lighting, while the robot keeps a constant stand off distance and near normal viewing angle to suppress glare.

Each image is then routed through a preprocessing pipeline that corrects lens distortion, converts to an illumination invariant colour space, and applies adaptive contrast enhancement to offset any residual lighting variation. The normalized output is distilled into colour texture embeddings and compared against a deep learning database trained on reference paint samples. This workflow unites precise robot positioning with

data driven evaluation, delivering consistent, objective paint inspection across complex body geometries.

Fig.2 Mobile robot manipulator color inspection

Ⅲ. Conclusion and Future Work

The normalized RGB histograms from three different vehicle viewpoints exhibit near-identical, sharp peaks in the red channel while green and blue remain negligible (see Fig.3). This consistent profile confirms that the paint's reflectance can be characterized reliably by its red component. The proposed histogram-based color-matching technique overcomes the angular and operator variability of traditional fixed or handheld systems, delivering automated, viewpoint-independent measurements that enhance accuracy and reduce human dependency in automotive paint quality

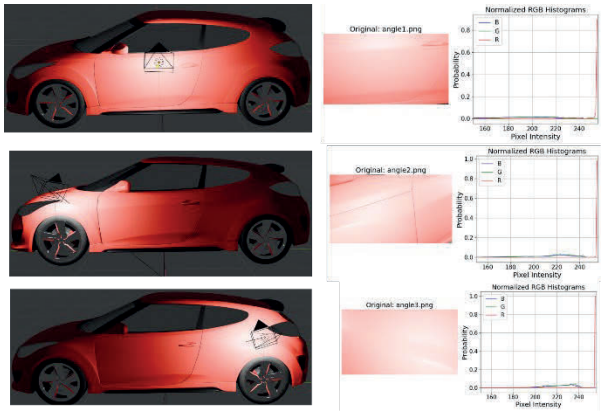

Fig.3 Color histogram in three different camera angle

In addition, the color detection network will be extended into a multimodal model that fuses spectral data with spatial context captured along the robot's trajectory, enabling real time identification of subtler paint variations and emerging defects-control workflows.

ACKNOWLEDGMENT

This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2025-RS-2024-00437190) supervised by the IITP(Institute for Information & Communications Technology Planning & Evaluation, 50%. This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the ICAN(ICT Challenge and Advanced Network of HRD) program(IITP-2025-RS-2022-00156394) supervised by the IITP(Institute of Information & Communications Technology Planning & Evaluation, 50%}

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