Novel AI techniques in dealing with manufacturing variations for automobile assembly systems

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Industry Challenge

With increased competition, globalization and uncertainty of today's markets, the manufacturing enterprises are facing more challenges in producing the desired products more efficiently. The state-of-the-art techniques such as machine vision and artificial intelligent (AI) techniques, allow manufacturing systems to learn from big data in order to realize a connected and intelligent industrial practice, known as smart manufacturing. By 2030, the global smart manufacturing market size is expected to reach £630 billion growing at annual growth rate of 12%. Part variations in geometry and surface finishes in manufacturing are a common phenomenon and those discrepancies adversely affect body assembly quality, functionality, cost and time-to-market. it is claimed that the earlier the defect is detected, the less cost will be spent to fix the defect. The American Society for Quality (ASQ) suggests that the Cost of Quality ranges between 15 – 20% of sales. According to AGCS analysis, over £11 million have been cost for defective product recall by automobile companies. Therefore, detection of these defects before products delivery is important to reduce cost as well as improve market reputation.

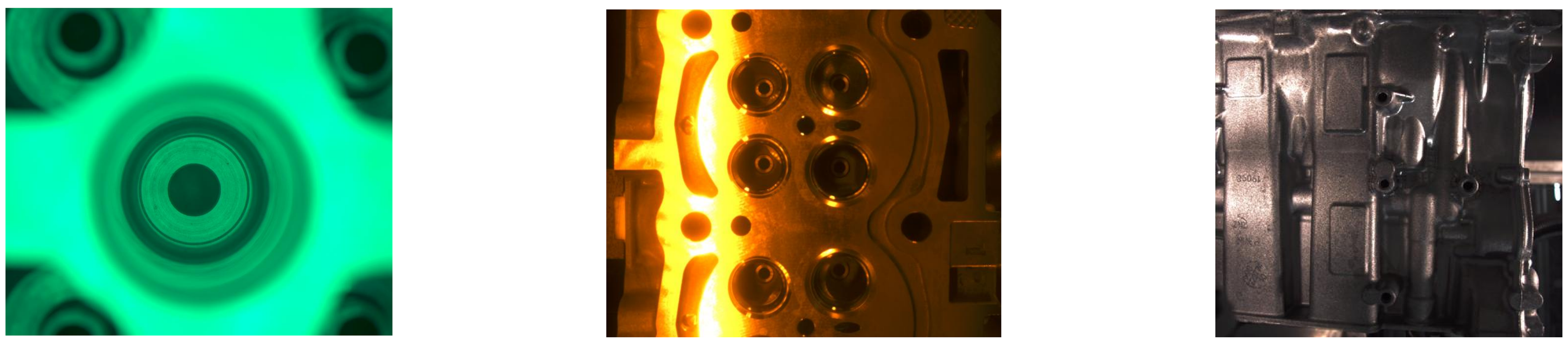

Figure 1. Sample car parts images captured at production line using different cameras and filters

Proposed Research

This project is carried out with collaboration between University of Strathclyde in UK and Stellantis in France, started from January 2020. The goal of this project is to detect the manufacturing variations with only the normal data of cylinder head via machine vision and artificial intelligence. The cylinder head images collected in Stellantis laboratory are sent to the Department of Design, Manufacturing, and Engineering Management for analysis with the state-of-the-art computer vision and AI techniques.

1) Data collection

The cylinder head images are collected with a set of cameras at fixed positions perpendicular to the combustion chamber face. To reduce the impact of metal surface reflection, the polarizing filters are attached in front of the camera lens. The target anomaly types to be detected are porosity and dent.

2) Anomaly Detection

The anomaly detection process is based on convolution neural network and digital image process techniques, consisting of the following parts:

- Pre-process images with image alignment and augmentation during training and only image alignment when inference.
- Fit Gaussian mixture model (GMM) for feature embeddings at different image location from a pretrained ResNet-18 model.
- Generate anomaly map of tested image by fusing two set of GMMs trained with image resolution of 512x512 and 1024x1024 for inference.
- Refine the mask with pixel-level image segmentation method

The whole process of both model training and inference is shown in Figure 2.

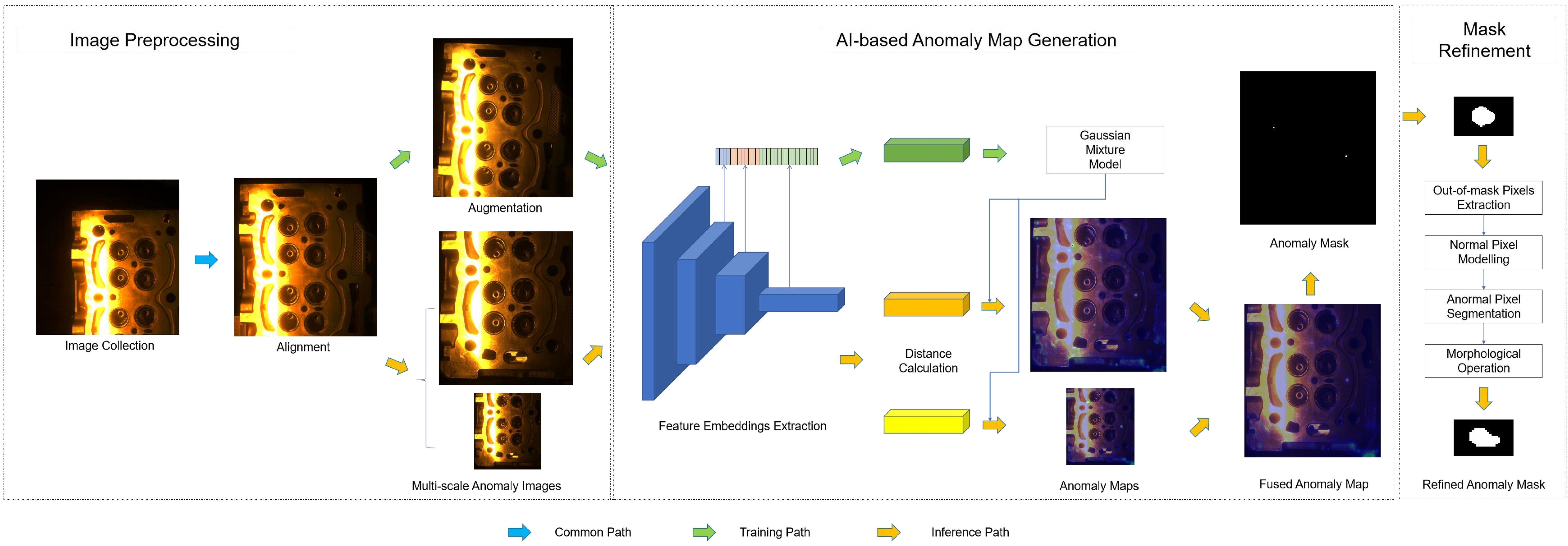

Figure 2. The whole process for anomaly detection on combustion chamber face of cylinder head

3) Evaluation

To evaluate the detection algorithm, the 15 anomaly images are passed to the model to generate anomaly mask. The generated mask is compared with the ground truth labelled by hand. Four metrics are used to evaluate the prediction accuracy, including the AUROC and F1 score at image level and pixel level respectively, as shown in Table 1. A sample anomaly detection of small dents is shown in Figure 3. It is shown that the fused method has obtained the best prediction performance and the mask refinement method

Table 1. The comparison results of the models with different input resolution

Image Resolution	Image AUROC	Image F1 Score	Pixel AUROC	Pixel F1 Score
512	0.8821	0.7096	0.9993	0.2337
1024	0.9161	0.7500	0.9988	0.2628
Fused	**0.9577**	**0.8182**	**0.9996**	**0.2805**

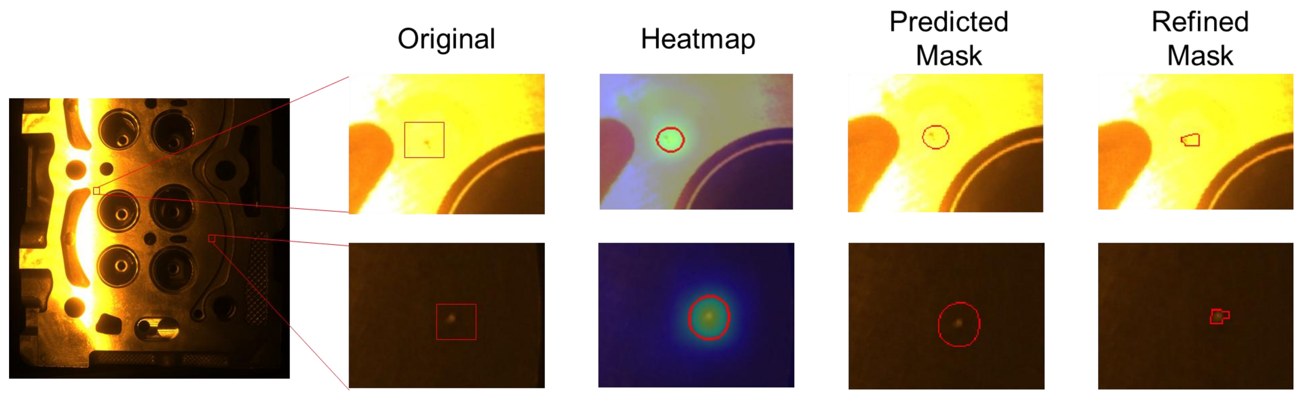

Figure 3. Sample anomaly detection of small dents

Outcomes

- An automated anomaly detection system is used for small anomaly detection such as porosity and dent on the cylinder head combustion surface.
- The image pre-processing, multi-scale fusion, and mask refinement methods extended the Padim method and increased the detection accuracy.
- The proposed anomaly detection method is validated to be successful even using only the anomaly-free images for training.

The future work:

- Develop stereo image based anomaly detection system to address the uneven lighting problem.
- Modify the current image acquisition system and develop anomaly detection software for the real engine production line.
- Improve the anomaly detection model to meet the real-time on-site detection requirement.

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