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A Low-Cost AI Defect Detection solution for SMEs

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The project is the first to

Develop a fully automated inspection solution for robotic glue deposition procedures utilising Siamese Neural Networks (SNNs) deployed on low-cost edge computing devices.

Computer Vision in Quality Control

Visual inspections, used to detect flaws visible to the human eye, remain the most commonly used method of non-destructive testing (NDT) across all manufacturing sectors. However, the effectiveness of manual inspection procedures is subject to significant variation as a result of complex interactions between organisational, social, environmental, and psychophysical factors. Advancements in Computer Vision (CV) methods, combined with the need to reduce variation in quality control activity are driving the automation of such procedures, reducing associated costs while simultaneously improving inspection performance.

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The field of computer vision has witnessed a paradigm shift in recent years, moving away from conventional/handcrafted algorithms, toward AI-enabled solutions. Deep Learning (DL) approaches have been shown to offer improved discriminative power and are considered more robust when exposed to sources of interference, interclass and intraclass variation.

The Challenge

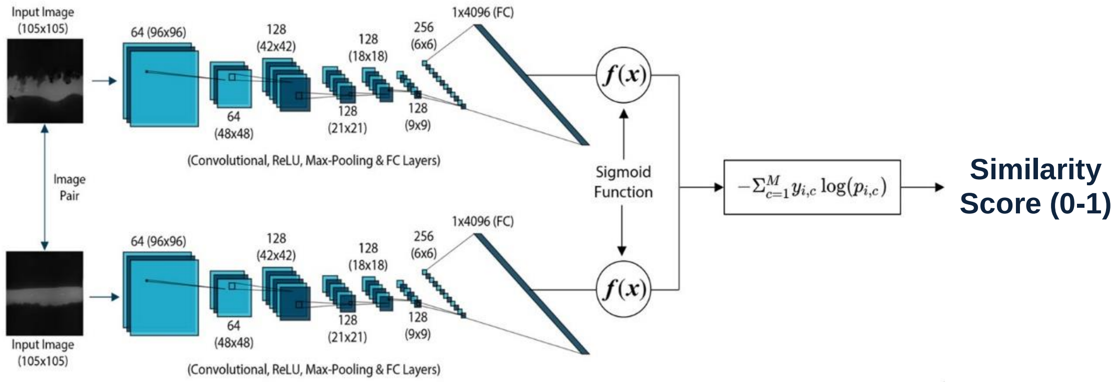
Developing automated solutions for glue bead inspection is challenging for a number of reasons:

- Defects rarely occur with a high degree of visual similarity.
- Conventional approaches rely on the development of numerous 'handcrafted' feature extraction algorithms for each defect type.
- Convolutional Neural Networks (CNNs) offer a plausible solution but require thousands of labelled training Images (per defect type) to achieve reliable performance.
- Defects are a rare occurrence, leading to a paucity of data for training DL models.

Research Questions

1. Can Siamese Neural Networks (SNNs) challenge the data availability problem in automated defect detection, and thus reliably identify glue bead defects?
2. Can these SNN models be deployed using low-cost edge computing devices?

SNN Model Architecture



(Koch, G. R., Zemel, R., & Salakhutdinov, R. (2015). Siamese Neural Networks for One-Shot Image Recognition)

The model architecture utilised in this study comprises two identical 13-Layer Convolutional Subnetworks, first developed by (Koch et al., 2015). By comparing similarity to the nominal (non-defective) state rather than assigning images to discrete classes, it is possible to detect new (unseen) defect types without retraining the network.

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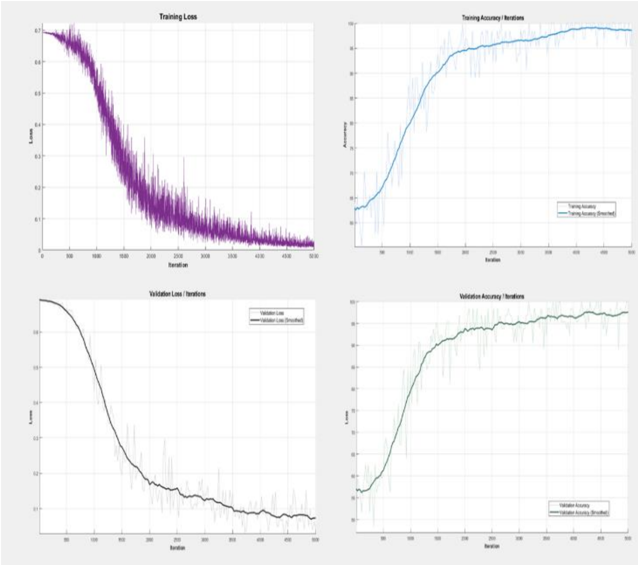
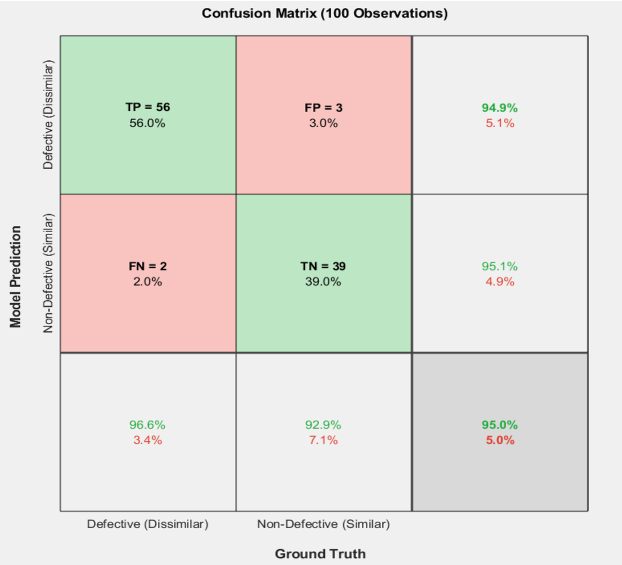
Summary of Results

Training Plots



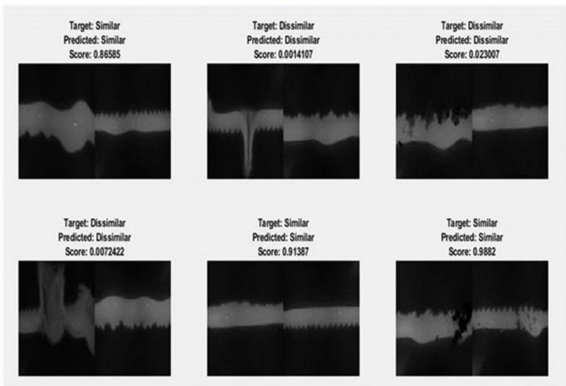
Inference Testing (Nvidia Jetson Nano)



(Model trained on Nvidia 3080Ti GPU and deployed on Nvidia Jetson Nano 4GB)

- Model trained using only one hundred observations per class (defective/non-defective).
- Model evaluated using K-Fold cross-validation (K=5).
- Max classification accuracy = 97.6% (mean avg. = 95.38%).
- Model deployed on an Nvidia Jetson Nano single board computer (SBC) using TensorRT Via Open Neural Network Exchange (ONNX).
- Inference accuracy on Jetson Nano = 95%
- Mean inference time of 122ms (≈8fps).
- Total cost of image acquisition & processing hardware = £145.65

Fold	Accuracy (%)	Precision	Recall	F1
1	97.6	0.933	1	0.965
2	96.1	1	0.950	0.974
3	92.0	0.857	1	0.923
4	96.0	1	0.947	0.973
5	94.7	0.910	1	0.953
Mean	95.28	0.94	0.98	0.96



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Key Finding 1

Using Siamese Neural Networks to challenge the data paucity problem in automated quality control / defect detection procedures is feasible. Defects can be detected with a mean accuracy of 95 percent with as few as one hundred training images per class.

Key Finding 2

Siamese network models can be effectively deployed using low-cost, commercially available edge computing devices, thus challenging cost as a barrier to entry. However, work remains in optimising these models to further improve runtime performance.

Wider Applications

Although this project focused on the development of an automated defect detection solution for a robotic glue deposition procedure, the insights gained are applicable to any quality control activity that requires visual inspection. Work is underway to investigate the model's capability to identify defects during the manufacture of printed circuit boards (PCBs).

The aim is to develop a flexible, end-to-end solution that enables production operatives to efficiently compile new datasets and thus train defect detection models for a number of component and product types with minimal intervention.

What's Next?

We are currently working closely with the process development team at Fibrax to evaluate the automated inspection solution under operational conditions within a robot cell. The next phase of the project will involve establishing secure communication between the edge computing device (Jetson Nano) and the industrial computer systems on-site using OPC Unified Architecture.

Further work will also include:

- Evaluating the model's defect detection performance using a wider range of training dataset sizes to obtain greater insight into sensitivity.
- Investigating the effect of various dataset augmentation strategies on classification accuracy in contrastive models.
- Testing the model's performance in a number of defect detection scenarios for varying product lines/types.
- Investigating optimisation strategies to improve the model's runtime performance on edge AI devices.

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