INSTITUTIONEN FÖR DATAVETENSKAP | LUNDS TEKNISKA HÖGSKOLA | PRESENTERAD 2024-04-02

EXAMENSARBETE Deep Learning For Anomaly Detection in Manufacturing Equipment
STUDENT Gustav Tindberg
HANDLEDARE Marcus Klang (LTH), Robert Hansson (Tetra Pak Packaging Solutions AB)
EXAMINATOR Jacek Malec (LTH)

PDA-RAE: AI-Driven Anomaly Detection for Smart Manufacturing Equipment

POPULÄRVETENSKAPLIG SAMMANFATTNING **Gustav Tindberg**

Deep learning methods, such as the proposed PDA-RAE model, effectively detect anomalies in cyclic manufacturing tasks. Through explainable AI techniques and rigorous evaluation, the trained model can highlight critical parts of the cycle, identifying influential variables and time steps that appear to impact outcome quality.

Industry 4.0 aims to revolutionize manufacturing through smart, data-driven automation. Manufacturing equipment executes highly precise and repetitive cycles, generating large amounts of segmented time-series data. The PDA-RAE model is proposed as a deep learning solution to analyze these cyclic multivariate time-series. Using the PDA feature extractor and a residual CNN-based autoencoder the model is excellent at finding useful features and compressing the information into an encoded representation. The model has successfully been applied to both anomaly detection and multi-class classification tasks.

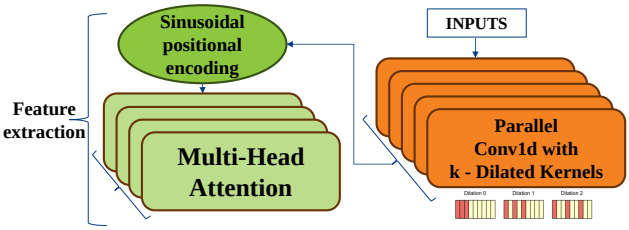

Figure 1: PDA Feature Extractor

The **PDA feature extractor** processes input sequences using parallel dilated convolutions, which capture patterns at multiple scales by analyzing different time intervals. The extracted features are then refined by a multi-head attention module, which highlights key patterns and relationships across variables. Additionally, sinusoidal positional encoding provides temporal context, improving the model's ability to detect long-term dependencies. Without the PDA, the model's reconstruction quality degrades to a level comparable to adding 12% random noise to the input sequence.

Table 1: Baseline comparison results

Model	Macro F1	Macro Recall	Macro Precision	MCC
PDA-RAE	0.91	1.00	0.85	0.835
A-LSTMAE	0.85	0.93	0.80	0.710
PCA	0.79	0.85	0.75	0.590
CNN-VAE	0.72	0.92	0.65	0.500
LSTM-VAE	0.52	0.51	0.52	0.091
Abs distance baseline	0.85	0.93	0.80	0.715

The PDA-RAE model was able to detect all known anomalies and several "near misses", potential faults missed by standard measuring equipment. Additionally, by combining explainable AI with human domain expertise, we can identify new insights, increase confidence in the models predictions, and provide foundations for future equipment development.