Siamese Networks for Unsupervised Failure Detection in Smart Industry

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Scenario

- **Goal:** Identify anomalous behavior (i.e., failures) in streaming data coming from IoT sensors installed on critical devices

- **Idea:** Develop a failure detection system based on an unsupervised deep learning model

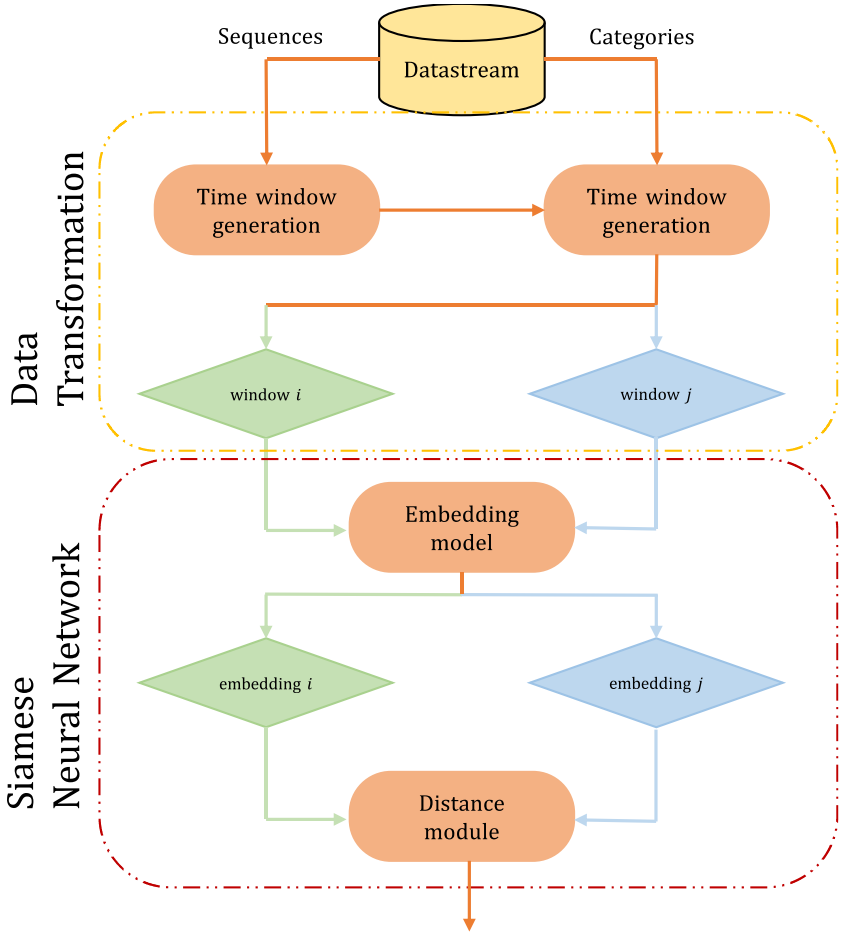
- **Solution**: Combining a data transformation approach with the learning of Siamese Neural Network

Problem Definition

- **Data**: a temporal sequence of events
  - Each event is represented by a feature vector containing the values observed by the sensors
  - Each sequence is labeled by a specific category which characterizes the process being monitoring
- A **failure** is an anomalous element that is distant from all the clusters of normal behavior
- **Goal**: detecting anomalous behaviors within a sequence associated with a device

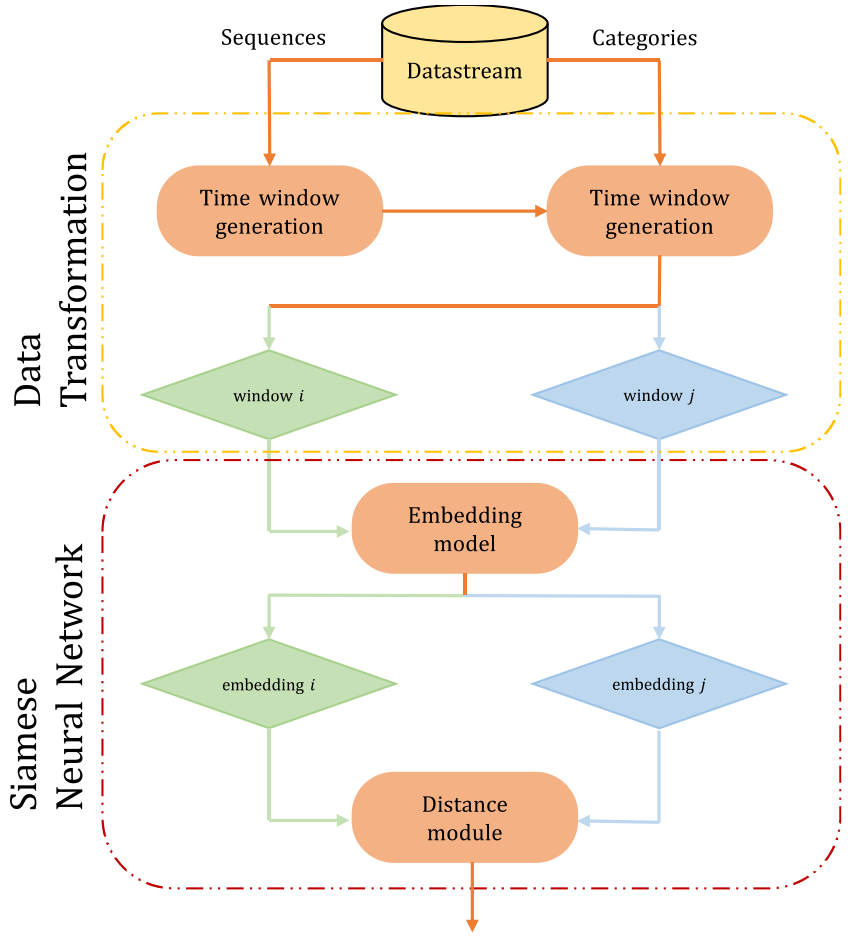
Methodology Overview

- Applies a **sliding window procedure** to generate, for each sequence, a set of fixed-size observation windows
  - Each window is a time frame that partially describes the behavior of the target devices during the interval of observation
- A **category** describes a situation that the sensors are measuring, e.g., an elevator moving up with a load of two persons
  - Elements marked with a specific category are different from elements labeled with a different one



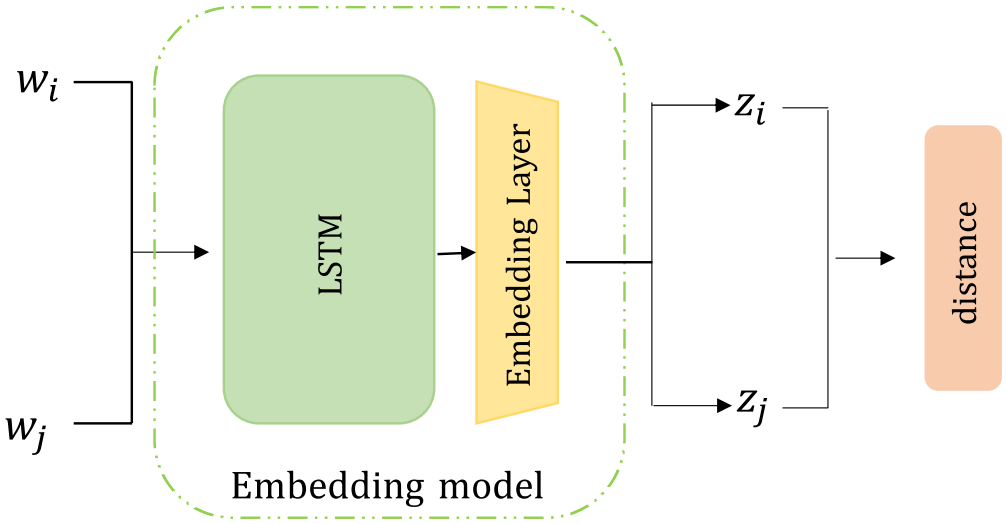
Methodology Overview

- A **Siamese Neural Network** is adopted to map the input (sequence fragments) into data points lying on a latent space
  - Data that belong to the same category are located in the same area with respect to data that belong to different category



Siamese Neural Network

- Siamese Neural Network is composed by two modules:
  - *Embedding subnet* that maps a time window into the latent space
  - *Distance subnet* that outputs the Euclidean distance between two embeddings
- The *Embedding subnet* is a sequential model composed by a recurrent neural network
  - Long Short-Term Memory (LSTM) is used



Siamese Neural Network

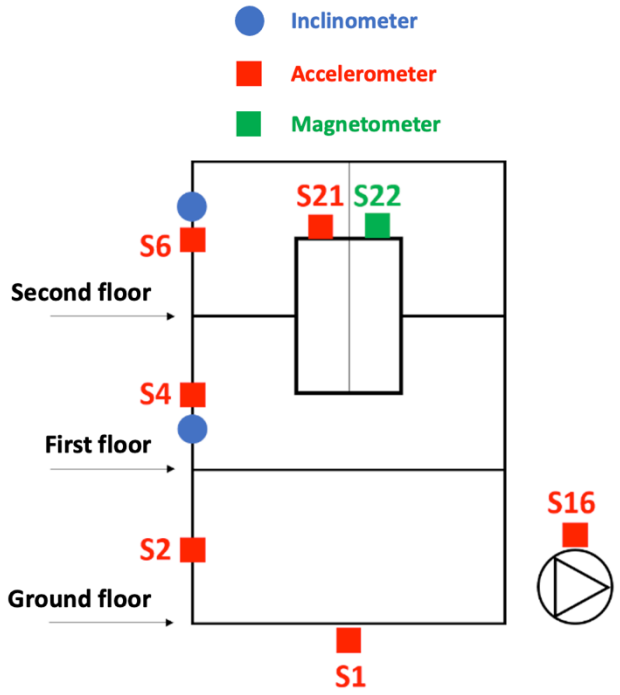
- The loss function is defined as follow:

$$loss = \frac{1}{|\mathscr{W}_s|} \sum_{w_i, w_j \in \mathscr{W}_s} y_{i,j} \cdot f(w_i, w_j) - (1 - y_{i,j}) \cdot \log\left(1 - e^{-f(w_i w_j)}\right)$$

- The following loss function encourages the network to generate pairs of embeddings that are close in the latent space if the two categories are the same, otherwise the network will produce pairs of embeddings that are distant

Case Study

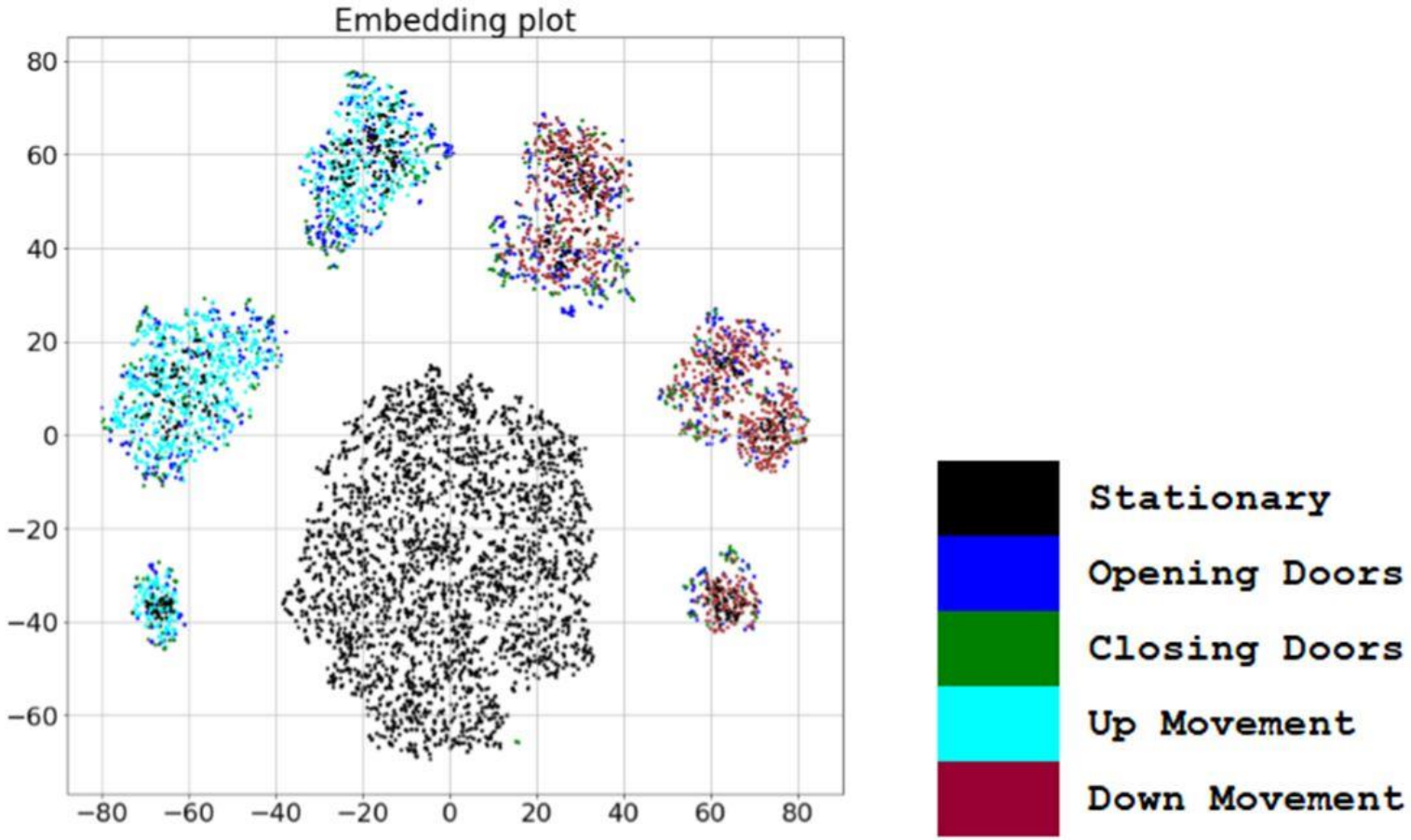
- The proposed model has been exploited to monitor the health status and the working process of an elevator in an office building



- The sensor system placed in the elevator records the movements in the x, y and z axes of the oscillations of the elevator guides and cabin, the inclination of the cabin and the magnetic field intensity
- The category labels were the operational modalities: (i) Stationary; (ii) Moving up; (iii) Moving down; (iv) Opening doors; (v) Closing doors
  - Each of these modalities is further labeled by the load (number of people) in the lift.

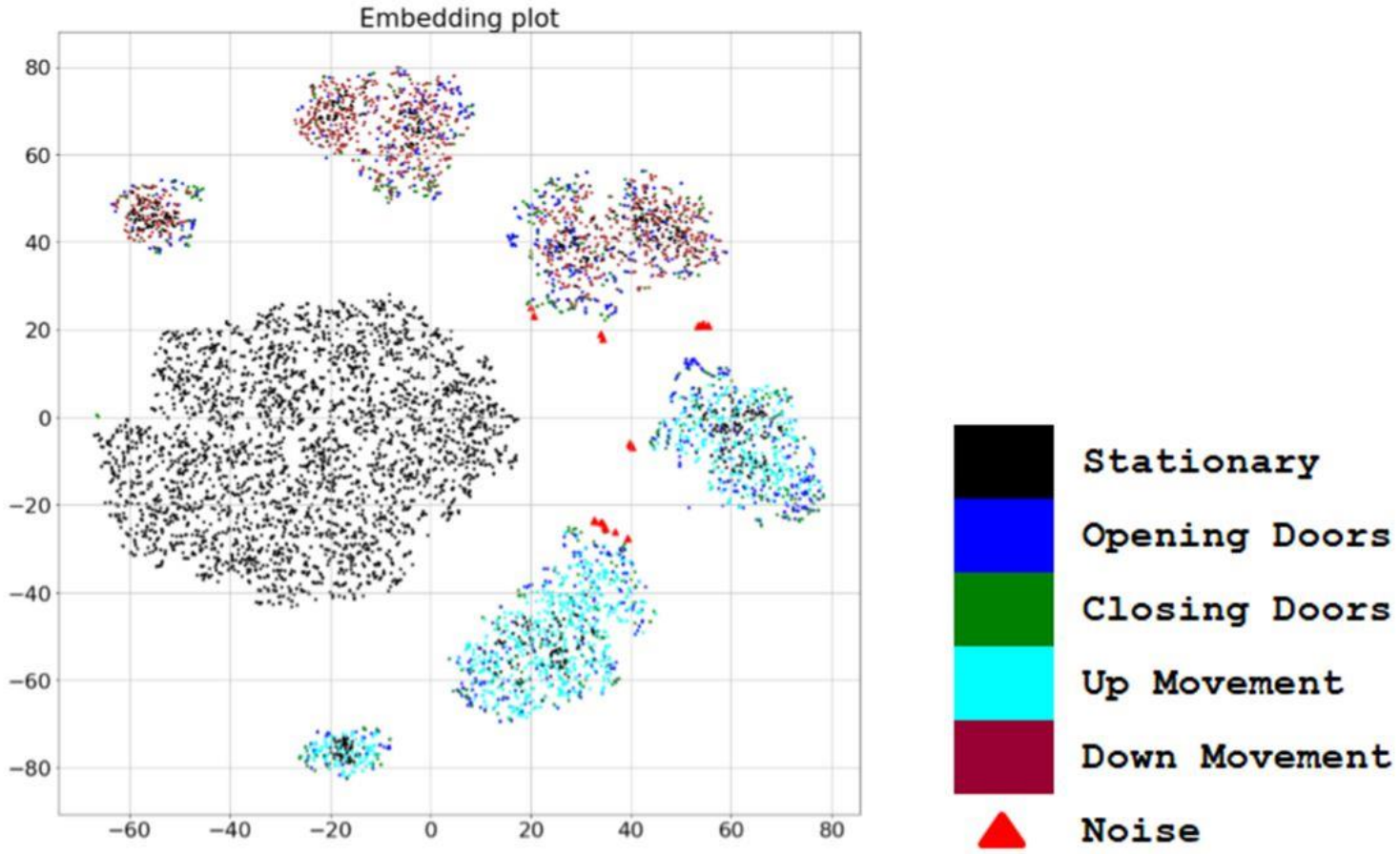
Experiments

- **RQ1**. Is the model able to perfectly separate the different normality patterns?



Experiments

- **RQ2**. Is the Siamese-based approach effective in detecting anomalous situations?



Conclusion

- We proposed an unsupervised failure detection
- The proposed methodology can support a maintenance expert in easily identifying failures as anomalous elements that are distant from all the clusters of normal behavior
- We evaluate the model on a real case study
- Experiments prove the capability of the model in effectively isolating anomalous time frames

Thank You for your attention!

Questions?

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