# System and method to detect anomalies in a steel wire rope (SWR) of an elevator based on changes in raw magnetic flux leakage (MFL) data

## FIELD OF THE INVENTION

[0001] The present invention relates to system and method for detecting anomalies in a steel wire rope (SWR) for elevator based on changes in raw magnetic flux leakage (MFL) data, in particular, a system and method for detecting and processing MFL data in detecting anomalies in SWR for elevators based on the MFL data collected.

## BACKGROUND OF THE INVENTION

[0002] Steel wire ropes (SWRs) are widely used in modern infrastructures such as bridges, mines, cranes, elevators, etc. An SWR is a complex mechanical component. It consists of strands that comprise small metal wires. The meticulous structure of an SWR gives it great strength yet high flexibility. A typical elevator uses a set of more than two SWRs to connect the lift car and counterbalance. First, an SWR circles a wire rope drum that connects to a rotor. The rotor rotates and displaces the lift car. Another independent SWR called the governor rope protects the lift system from overspeed. Since elevators are safety-critical, failures of SWR may cause serious injuries or even death. It imposes a serious demand for an accurate and suitable fault detection system for SWR to ensure the safe operation of the lift system.

[0003] An effective fault detection mechanism is the prerequisite of any maintenance scheme. The conventional approach in searching for faults or anomalies of SWRs in lift systems usually employ manual tools and safety operators' visual inspections. The safety operators with their bare eyes search for defects which are listed on the discard or replacement criteria stated in international standards such as ISO4344, national regulations, and manufacturer's manual. Common defects of the SWR include broken wires, reduction in diameter (wearing, abrasion), fretting corrosions (rouging, rusting), and other anomalies. Human inspections, however, are prone to significant systematic errors induced by the potential poor vision of the safety operator or the lack of operating experience.

[0004] Such defects in SWRs that are not appropriately handled would lead to severe incidents for lift systems. For instance, it was reported that a lift-system accident happened in North Point, Hong Kong, where all SWRs broke simultaneously. It was later found that the accident occurred just 101 days after the regular maintenance because the safety operators could not spot the defects in the SWRs. This example showed that the human-based anomaly detection method would sometimes be unreliable.

[0005] Conventional techniques include inspecting SWRs conditions by using advanced non-destructive testing (NDT) method. Some common NDT methods include computer vision, acoustic emissions, ultrasonic-guided waves, radiography, and electromagnetic methods. In particular, the electromagnetic methods are further divided into eddy current testing and magnetic flux leakage (MFL) detection. MFL detection is one of the most common NDT methods employed. However, the typical MFL signals are presented in waveforms, which are difficult for safety operators to interpret. Hence, there is a need for a system to analyze the waveforms into information that displays the location of the defects, the type of defects and the actions required thereafter. The diagnostic system has to be automatic and robust.

[0006] MFL signals are presented by graphic lines in typical MFL systems, in which an algorithm indicates local flaw damage (LF) and loss of metallic cross-sectional area (LMA) based on the voltage values. However, noises due to strand configurations, other electromechanical modules, and other environmental factors would sometimes make the systems unable to identify defects (false negatives) or detect flaws incorrectly (false positives). A binary classification based on MFL voltage waveform needs to be robust to tell whether SWR flaws are present. Also, LF and LMA does not distinguish the exact type of the detected defects. Regulations of lift systems require quantitative measurement of the defects (e.g., the number of broken wires on one strand, the total number of broken wires distributed in a lay length), which is not given by a typical MFL system. Still, one needs human inspection for compliant determination. This issue is proposed to be resolved by combining direct imaging with human inspections from others. However, SWR connecting to a lift system cannot be uninstalled easily, and imaging SWR shall be performed inside the lift system. The dark environment also makes imaging difficult. Including an illumination system might work, but lubricant on the surface of the SWR might reflect and distort light, making imaging SWR an inconsistent and possible problematic task.

[0007] Due to the lack of robustness of the vision-based fault detection method, many research are done to tackle the above situation by combining machine-based fault detection with human-based diagnosis to improve the reliability of the anomaly detection algorithm. For example, China Patent CN115081485 A discusses an AI-based automatic analysis method for magnetic flux leakage internal detection data including constructing an automatic analysis quantification model based on the detection sample data and the AI model in the pipeline; generating corresponding artificial intelligence data analysis software based on the automatic analysis quantification model; constructing a corresponding intelligent analysis and evaluation system based on the artificial intelligent data analysis software and the pipeline integrity management system; obtaining a corresponding magnetic flux leakage data analysis result based on the current detection data in the pipeline. However, despite the said system involves sophisticated signal transformation and reconstruction process, the exact type and quantitative assessment of flaws at the targeted SWR are still undeterminable. Additionally, there is a likelihood of data loss due to the complex structure of the overall system.

[0008] Additionally, China Patent No. CN111862083A discussed a steel wire rope state comprehensive monitoring system and method based on visual-electromagnetic detection. The method comprises the following steps: detecting wire breakage, abrasion and corrosion damage on the surface of a steel wire rope through a machine vision method, recognizing the steel wire rope with normal and abnormal appearance in a self-adaptive mode through a deep convolutional neural network, and accurately recognizing the type and position of surface damage through a yolov3 algorithm of an improved main network. With its complicated system, there is a likelihood of data loss, hence reducing the accuracy of the outputs. Besides, the system further required an image acquisition device for acquiring images in the rope system, which imaging of SWR shall be taken inside the lift system. Hence, there is also a need for light for visual purposes and due to the dark environment and the presence of lubricant on the surface of the SWR, the images displayed may not be accurate.

[0009] Whilst there are other studies to detect flaws in SWRs i.e., relying upon SWR images, processing MFL data and passing them into a state-of-the-art machine learning framework for anomaly detection with high accuracy, such methods require sophisticated signal processing and transformation. The transformed signal might suffer from information loss. These methods also need to be more robust for different types of SWR MFL data. The transformed data also possess non-intuitive graphic meaning to operators. Furthermore, most of their data collection is done in a well-prepared laboratory state, with equipment perfectly fit for collecting MFL data of one SWR. This is not usually guaranteed in a lift system.

[0010] Therefore, there is a need to have a low-cost system and method that detect and process data input efficiently with minimal data loss and reduces human touch in order to determine the type and location of a faulty SWR in an elevator system for the safety of the users which at the same time satisfies the regulatory requirement for a safe elevator. Additionally, the said system and method need to be highly accurate, intelligent and efficient in detecting anomalies in a steel wire rope (SWR) for elevators.

## SUMMARY OF THE INVENTION

[0011] It is an objective of the present invention to detect and process raw magnetic flux leakage (MFL) data efficiently with minimal data loss and reduce human touch for minimizing human errors for anomalies detection in a steel wire rope (SWR) for elevators.

[0012] It is also an objective of the present invention to accurately identify the type of flaw and its classification based on the processed MFL data.

[0013] Accordingly, these objectives can be achieved by following the teachings of the present invention, which relates to a system configured to detect anomalies in a steel wire rope (SWR) of an elevator based on changes in raw magnetic flux leakage (MFL) data, the system comprises: at least one MFL signals sensor placed on a targeted SWR of the elevator; a pre-processing module configured to process the MFL data; at least one pre-trained deep learning neural network models configured to train the processed data and generate outputs; and a feedback module configured to record and feed the outputs back into the at least one pre-trained deep learning neural network models for parameters updates and re-training.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The features of the invention will be more readily understood and appreciated from the following detailed description when read in conjunction with the accompanying drawings of the preferred embodiment of the present invention, in which:

[0015] **Figure 1** illustrates an overview on the present invention;

[0016] **Figure 2** illustrates a flow chart on the processing and training of dataset comprising of MFL data;

[0017] **Figure 3** illustrates slicing and centering of raw MFL data; and

[0018] **Figure 4** illustrates smoothing and statistically transforming raw MFL data.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] For the purposes of promoting and understanding the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and described in the following written specification. It is understood that the present invention includes any alterations and modifications to the illustrated embodiments and includes further applications of the principles of the invention as would normally occur to one skilled in the art to which the invention pertains.

[0020] The present invention teaches a system **10** configured to detect anomalies in a steel wire rope (SWR) of an elevator based on changes in raw magnetic flux leakage (MFL) data, the system comprises: at least one MFL signals sensor placed on a targeted SWR of the elevator; a pre-processing module **14** configured to process the MFL data; at least one pre-trained deep learning neural network model **16**; and a feedback module configured to record and feed the outputs back into the at least one pre-trained deep learning neural network model **16**for parameters updates and re-training. This is further illustrated in **Figure 1.**

[0021] In an embodiment of the present invention, the MFL signals sensor is a Hall sensor that detects the MFL data as raw waveforms. It is very typical for MFL signals to be presented in waveforms. Hence, the system **10** is coupled with an Artificial Intelligence (AI)-based pipeline to process and analyse the MFL signals. The said pipeline could provide an accurate failure identification to operators for follow-up actions, and more importantly, it is automatic. The said AI is the deep learning neural network model **16** in the present invention.

[0022] In a preferred embodiment of the present invention, the pre-processing module further comprises an algorithm-based trimming module. This will allow data to be better fitted into the at least one pre-trained deep learning neural network model **16**.

[0023] In a preferred embodiment of the present invention, the at least one pre-trained deep learning neural network model **16** accepts multi-channel data input with no sophisticated transformation required, therefore, the present invention ensures minimal information loss with a simple pre-processing procedure.

[0024] The present invention also teaches a method for detecting anomalies in a steel wire rope (SWR) of an elevator based on changes in raw magnetic flux leakage (MFL) data, the method comprises: collecting at least one raw MFL data on a targeted SWR in the elevator; pre-processing the raw MFL data; using the processed data to train at least one deep learning neural network model **16**; generating outputs **18**; and recording and feeding the outputs back into the at least one deep learning neural network model **16** for updating the parameters and re-training the at least one deep learning neutral network model **16**. The process flow is illustrated in **Figure 2**.

[0025] In a preferred embodiment of the present invention, the generating outputs **18** comprises the step of using deep learning neural network model **16** to locate and identify flaws and anomalies on the targeted SWR. For example, in the absence of an anomaly, a trained binary classifier **161** in the warning layer identifies the targeted SWR as normal and moves on to the next position on the targeted SWR and if an anomaly is detected at the said position, the trained binary classifier **161** passes the data to a trained multi-class classifier **162** in the distinguishing layer to determine if the anomaly has a known defect or an unknown defect. Suggestions for the next course of actions for the operator will be provided by the trained binary classifier **161** based on the anomalies detected.

[0026] In a preferred embodiment of the present invention, the pre-processing of MFL data further comprises: slicing the raw MFL data by way of moving window with local minima centering and slicing such raw MFL data in windowed time series; and smoothing and statistically transforming the raw MFL data. In addition to the above, the raw MFL signals are smoothed with the Savitzky-Golay filter to mitigate discontinuity.

[0027] The Savitzky-Golay filter is a data-smoothing technique that averages time-domain data by a high-order polynomial within a window. In doing so, the present invention prevents bias caused by simply averaging data points with different magnitudes while preserving shapes and extrema associated with the time-series data.

[0028] **Figure 3** and **Figure 4** illustrate an overview of how the data are spliced, centered, smoothened and statistically transformed in the pre-processing module **14.**

[0029] In a preferred embodiment of the present invention, collecting of the raw MFL data comprises further collecting multi-channel raw MFL data.

[0030] Other advtanges of the present invention are that the present invention suits the needs of SWR safety checks inside lift systems where the ambient environment is dark, and the surface lubricant of SWR will not affect data collection procedure in the present invention.

[0031] The present invention explained above is not limited to the aforementioned embodiment and drawings, and it will be obvious to those having an ordinary skill in the art of the prevent invention that various replacements, deformations, and changes may be made without departing from the scope of the invention.

CLAIMS

WHAT IS CLAIMED:

1. A system (10) configured to detect anomalies in a steel wire rope (SWR) of an elevator based on changes in raw magnetic flux leakage (MFL) data, the system comprises:
   at least one MFL signals sensor placed on a targeted SWR of the elevator;
   a pre-processing module (14) configured to process the MFL data;
   at least one pre-trained deep learning neural network model (16); and
   a feedback module configured to record and feed the outputs back into the at least one pre-trained deep learning neural network model (16) for parameters updates and re-training.

2. The system as claimed in claim 1 wherein the MFL signals sensor is a Hall sensor that detects the MFL data as raw waveforms.

3. The system as claimed in claim 1 wherein the pre-processing module (14) further comprises an algorithm-based trimming module.

4. The system as claimed in claim 1 or 3 wherein the pre-processing module (14) processes the data for to be better fitted into the at least one pre-trained deep learning neural network model (16).

5. The system as claimed in claim 1 or 4 wherein the at least one pre-trained deep learning neural network model (16) accepts multi-channel data input.

6. A method for detecting anomalies in a steel wire rope (SWR) of an elevator based on magnetic flux leakage (MFL) data, the method comprises:
   collecting at least one raw MFL data on a targeted SWR in the elevator;
   pre-processing the raw MFL data;
   using the processed data to train at least one deep learning neural network model (16;
   generating outputs (18); and
   recording and feeding the outputs back into the at least one deep learning neural network model (16) for updating the parameters and re-training the at least one deep learning neural network model (16).

7. The method as claimed in claim 6 wherein the pre-processing of the raw MFL data further comprises:

slicing the raw MFL data by moving window with local minima centering and slicing such raw MFL data in windowed time series.

8. The method as claimed in claim 7 wherein the pre-processing of the raw MFL data further comprises:

   smoothing and statistically transforming the raw MFL data,

   wherein the smoothing of the raw MFL data is via deploying Savitzky-Golay filter and mitigating discontinuity.

9. The method as claimed in claim 6, 7 or 8, wherein the collecting of the raw MFL data comprises:

   further collecting multi-channel raw MFL data.

10. The method as claimed in claim 6 or 9, wherein the collecting of the raw MFL data is in a dark environment or environment without light.

11. The method as claimed in claim 6 or 10, wherein the generating outputs (18) comprises the step of using the deep learning neural network model (16) to locate and identify flaws and anomalies on the targeted SWR.

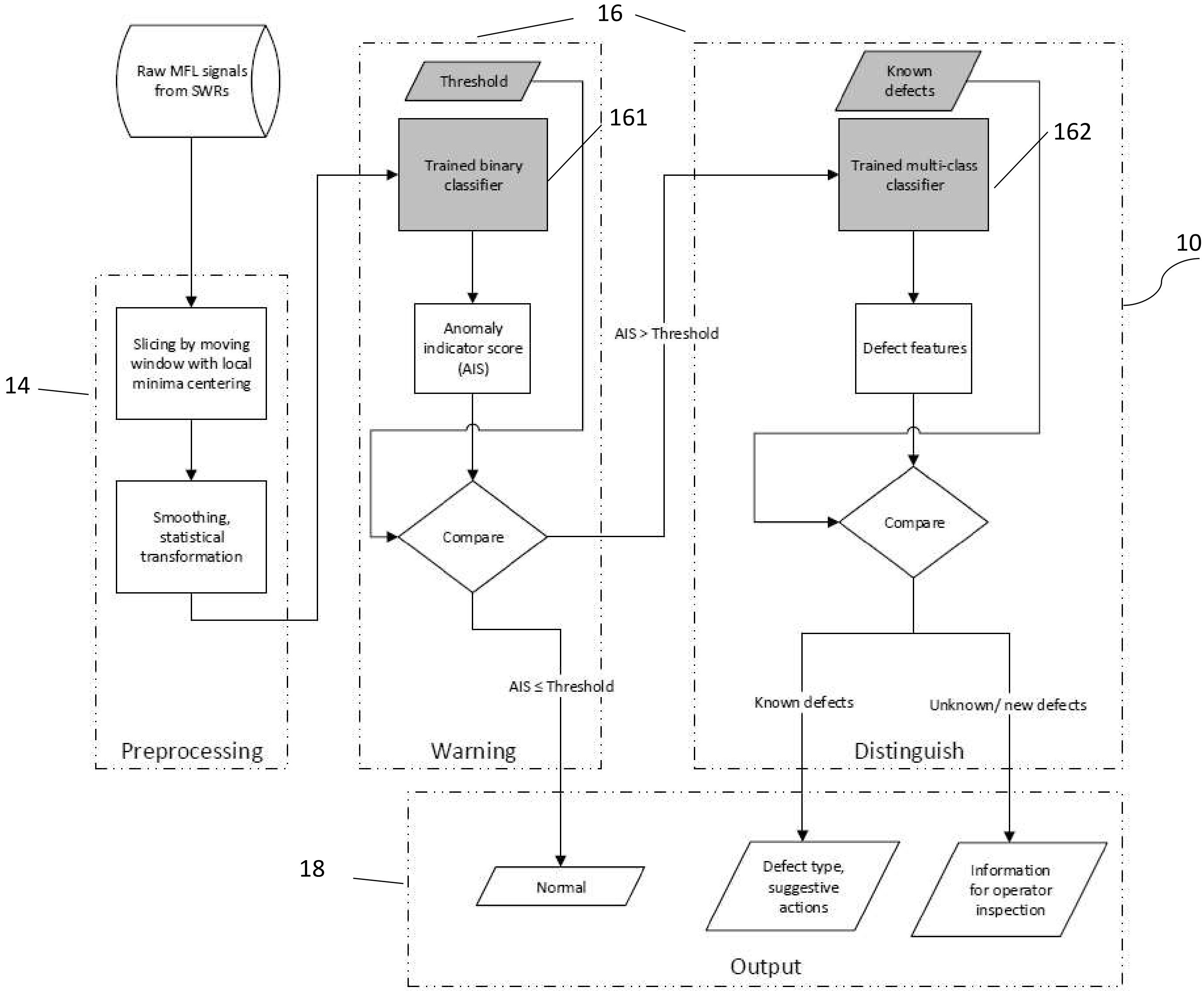
16
Raw MFL signals from SWRs
Threshold
Trained binary classifier
161
Known defects
Trained multi-class classifier
162
10
Slicing by moving window with local minima centering
14
Smoothing, statistical transformation
Anomaly indicator score (AIS)
AIS > Threshold
Defect features
Compare
Compare
AIS ≤ Threshold
Known defects
Unknown/ new defects
Preprocessing
Warning
Distinguish
18
Normal
Defect type, suggestive actions
Information for operator inspection
Output

Figure 1

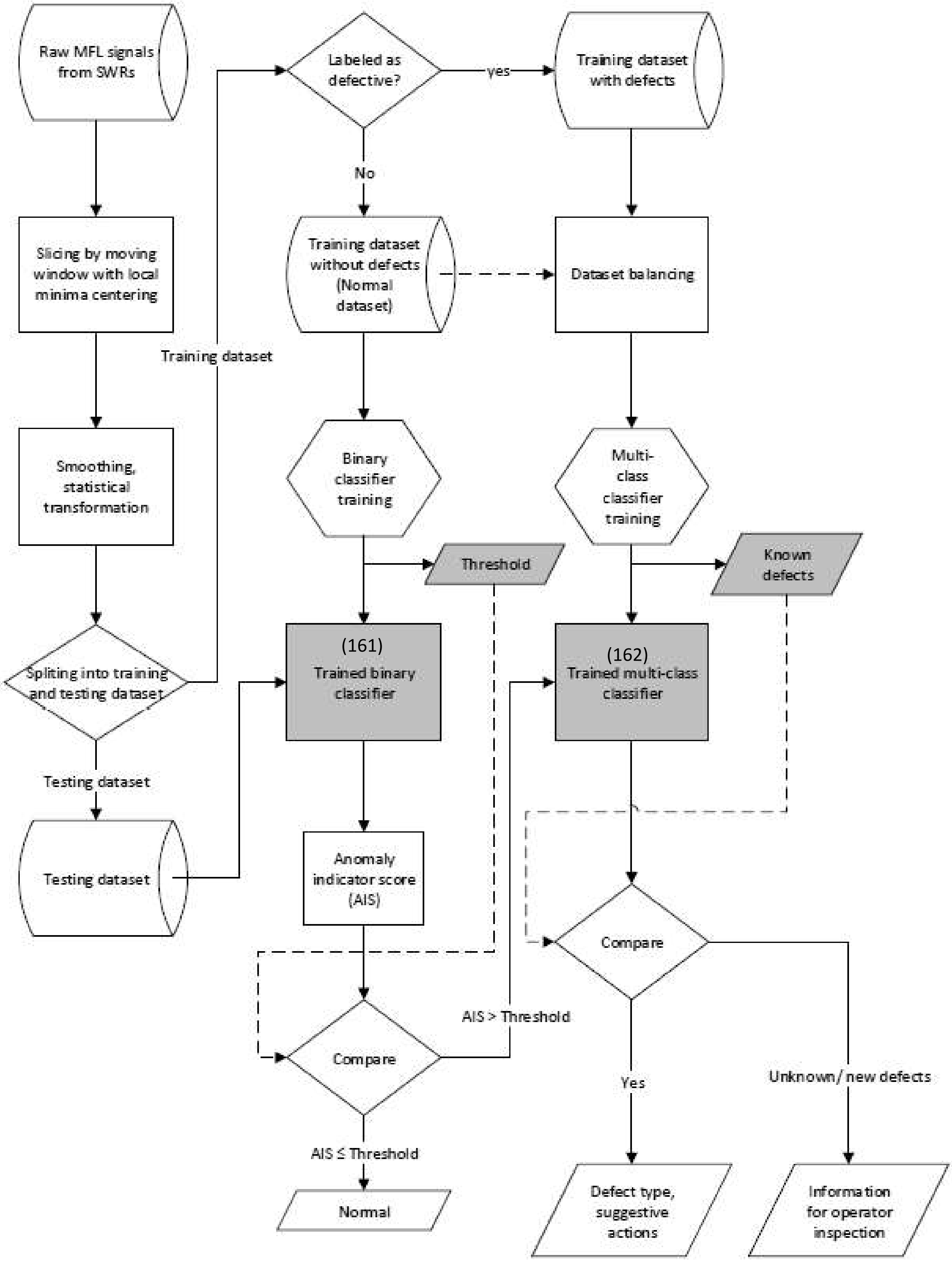
Raw MFL signals from SWRs
Slicing by moving window with local minima centering
Smoothing, statistical transformation
Spliting into training and testing dataset
Training dataset
Testing dataset
Testing dataset
Labeled as defective?
yes
No
Training dataset with defects
Training dataset without defects (Normal dataset)
Dataset balancing
Binary classifier training
Multi-class classifier training
Threshold
Known defects
(161)
Trained binary classifier
(162)
Trained multi-class classifier
Anomaly indicator score (AIS)
Compare
AIS > Threshold
AIS ≤ Threshold
Normal
Compare
Yes
Unknown/ new defects
Defect type, suggestive actions
Information for operator inspection

Figure 2

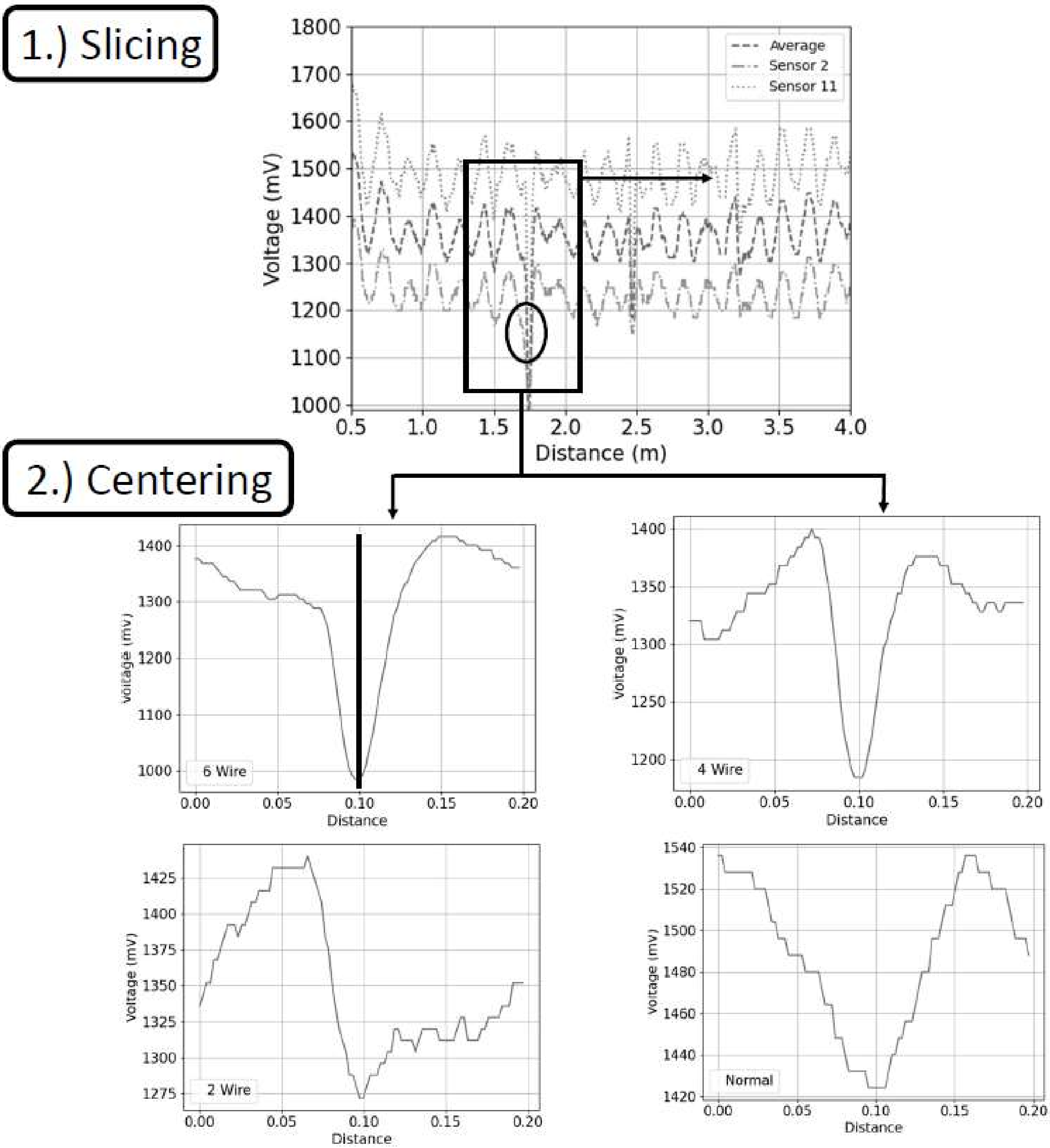
1.) Slicing
2.) Centering
Average
Sensor 2
Sensor 11
Voltage (mV)
Distance (m)
6 Wire
4 Wire
2 Wire
Normal
Distance


Figure 3

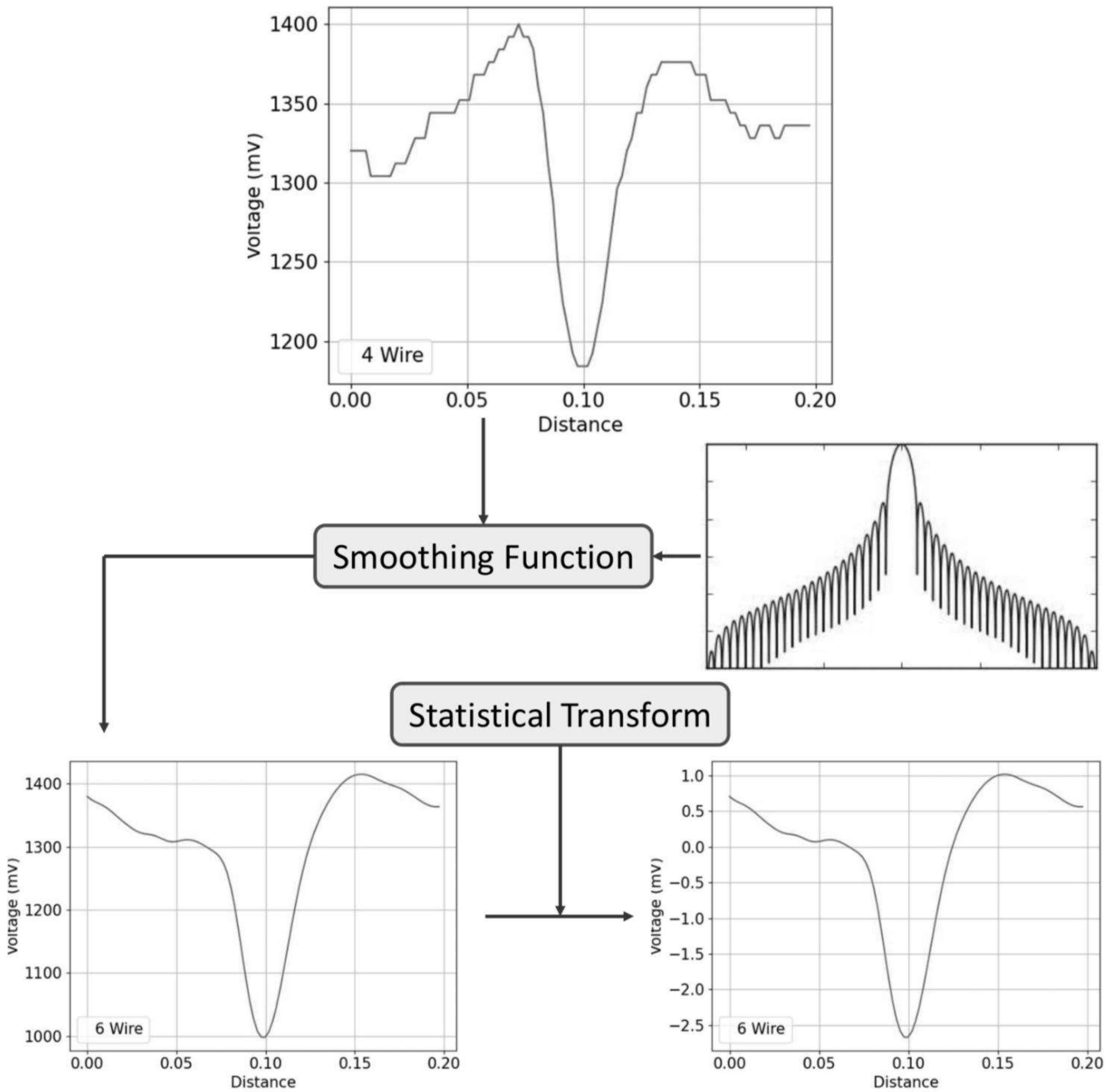
1400
1350
1300
1250
1200
Voltage (mV)
4 Wire
0.00
0.05
0.10
0.15
0.20
Distance
Smoothing Function
Statistical Transform
1400
1300
1200
1100
1000
Voltage (mV)
6 Wire
Distance
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
Voltage (mV)
6 Wire
Distance

Figure 4