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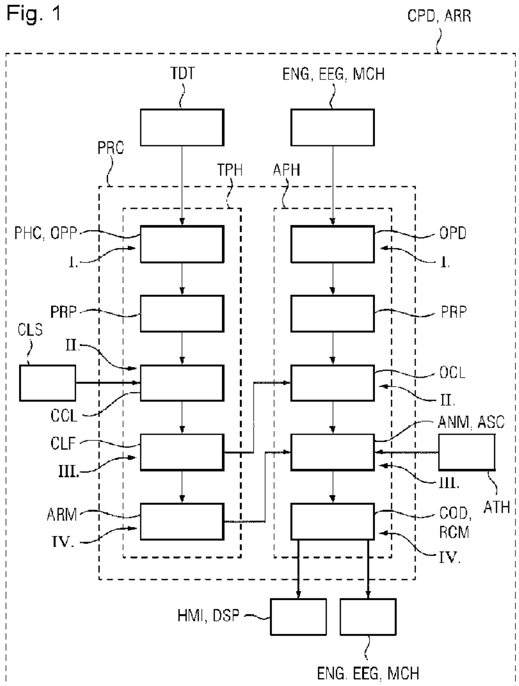
(54) Titre : PROCEDE DE SURVEILLANCE D'UNE MACHINE, PRODUIT PROGRAMME D'ORDINATEUR ET DISPOSITIF

(54) Title: METHOD FOR MONITORING A MACHINE, COMPUTER PROGRAM PRODUCT AND ARRANGEMENT

Fig. 1



(57) Abrégé/Abstract:
The invention relates to a method (PRC) for monitoring the operation of a machine (MCH), in particular of a motor (ENG) or electrically driven motor (EEG). To improve the monitoring, the method proposes a method of this type comprising the following steps: c) training phase (TPH): i. providing training data (TDT) comprising state variables (PHC) of multiple operating points (OPP) of the machine (MCH), ii. recognizing and combining operating points (OPP) in the training data (TDT) through clustering (CLS) to form operating-point clusters (OCL), iii. training a classifier (CLF), which assigns operating points (OPP) to the recognized operating-point clusters (OCL), iv. training an anomaly recognition model (ARM) for recognizing operating anomalies, d) application phase: i. recording operating data (OPD) comprising state variables (PHC) of operating points (OPP) of the machine (MCH) in an operating state, ii. assigning the operating data (OPD) to the operating-point clusters (OCL) using the classifier (CLF), recognizing operating anomalies using the anomaly recognition model (ARM).

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Abstract:

The invention relates to a method (PRC) for monitoring the operation of a machine (MCH), in particular of a motor (ENG) or electrically driven motor (EEG). To improve the monitoring, the method proposes a method of this type comprising the following steps: c) training phase (TPH): i. providing training data (TDT) comprising state variables (PHC) of multiple operating points (OPP) of the machine (MCH), ii. recognizing and combining operating points (OPP) in the training data (TDT) through clustering (CLS) to form operating-point clusters (OCL), iii. training a classifier (CLF), which assigns operating points (OPP) to the recognized operating-point clusters (OCL), iv. training an anomaly recognition model (ARM) for recognizing operating anomalies, d) application phase: i. recording operating data (OPD) comprising state variables (PHC) of operating points (OPP) of the machine (MCH) in an operating state, ii. assigning the operating data (OPD) to the operating-point clusters (OCL) using the classifier (CLF), recognizing operating anomalies using the anomaly recognition model (ARM).

Description

Method for monitoring a machine, computer program product and arrangement

The invention relates to a method for monitoring the operation of a machine, in particular of a motor or electrically driven motor.

Faults and anomalies may occur during the operation of machines, for example of drive systems. These problems may be caused by mechanics, but may also be down to electrical reasons and impact both the motor and the application. If these faults and changes are not recognized early, this leads to increased downtimes and additional and increased maintenance outlay. The monitoring of motor applications is therefore of critical importance for efficient, inexpensive and flexible production. However, this entails technical challenges:

1) Many machines, for example motor applications (such as pumps and fans) are inverter-driven and thereby have different operating points. During the state monitoring of such applications, the different operating points are typically not considered explicitly or operating point-dependent monitoring does not take place. This leads to faults only being detected too late or not being detected at all. It is likewise not possible to isolate the fault. In addition, the vibration may vary greatly depending on the operating point. Monitoring the general vibration level across all operating points possibly does not make it possible to recognize the different changes within one operating point and thus to detect the onset of damage.

2) Furthermore, during state monitoring, the constraints of the system are not considered, for example the application, interfering influences from the environment,

the installation, etc. These may influence the robustness and reliability of the state monitoring.

Motor applications (pumps, fans) are monitored by manually configuring limits that are based on standards. Drawing a distinction according to operating points does not exist at present. In this case, the constraints are not considered either.

Proceeding from the problems and disadvantages of the prior art, the invention set itself the problem of improving the monitoring of such machines, in particular of motors, and thus of preventing machine damage as a result of unfavorable operating conditions.

In order to improve monitoring, the invention proposes a method of the type defined at the outset, comprising the following steps:

a) training phase:
   i. providing training data comprising state variables of multiple operating points of the machine,
   ii. recognizing and combining operating points of the training data by way of clustering to form operating-point clusters,
   iii. training a classifier that assigns operating points to the recognized operating-point clusters,
   iv. training at least one anomaly recognition model to carry out operating anomaly recognition,

b) application phase:
   i. recording operating data comprising state variables of operating points of the machine in an operating state,
   ii. assigning the operating data to the operating-point clusters by way of the classifier,

iii. recognizing operating anomalies by way of the at least one anomaly recognition model.

In connection with the invention, a state variable is a macroscopic physical variable. State variables may be used to describe the state of a physical system. By way of example, this may involve thermodynamic pressure, temperature or else variables from other scientific disciplines, such as for example speed, force, torque, voltage, current, power output, efficiency or volume.

One advantageous variant of the invention makes provision for the at least one anomaly recognition model to be an unsupervised model.

An unsupervised model (see also in this regard https://de.wikipedia.org/wiki/Un%C3%BCberwachtes_Lernen) is understood by the invention to mean a model - that is to say a simplified portrayal of reality - that is designed to carry out machine learning without specific target values of the learning process being defined beforehand. In this case, the unsupervised model, in the input data, recognizes patterns that deviate from unstructured noise. One preferred option for implementing the unsupervised model consists in the use of artificial neural network algorithms. These are oriented toward the similarity of input values and adapt themselves accordingly. In this case, it is possible to automatically create a clustering (segmentation or grouping).

One advantageous variant of the invention makes provision for operating points to comprise measured values of at least one of the following types: vibration, temperature, torque, supplied power, output power, efficiency (for example electrical or thermal efficiency), energy consumption, electric current, voltage, frequency, supply voltage (in the case of inverter-fed electric motors).

One advantageous variant of the invention makes provision for the training data to comprise multiple operating points and/or historical data and/or reference measurements and/or fingerprints. These training data may originate from the same machine or a group of identical machines. It is also possible to use simulated data or data from similar machines. In this case, it may be expedient for the method to comprise further steps, in particular:

- preprocessing the training data and/or operating data by way of data cleansing and/or data scaling, in particular using further data sources and/or data from a digital twin and/or machine nominal values.

One advantageous variant of the invention makes provision for the at least one anomaly recognition model to calculate an anomaly characteristic value (or anomaly score) the value of which describes the severity of the anomaly, wherein an anomaly or an anomaly type is recognized when the anomaly characteristic value exceeds a predetermined threshold value. In this case, according to one advantageous variant of the invention, it is expedient for the anomaly or the anomaly type to be recognized as a faulty operating point, in particular for the anomaly recognition model to isolate the operating point at which the anomaly is visible or occurs. It may also be expedient to assign a respective one of different types of anomaly to an operating state based on the anomaly characteristic value and multiple threshold values, wherein each type of anomaly may have its own threshold value. By way of example, a low anomaly characteristic value may indicate a normal state, a medium one may indicate the need for a specific upcoming maintenance requirement and a high one may indicate the need to shut down the machine.

One advantageous variant of the invention makes provision for the method to comprise further steps:

- displaying the anomaly characteristic value and/or recommendations based on the anomaly characteristic value with regard to operating the machine and/or
- controlling, in particular automatically controlling the machine, such that the current operating point of the machine changes.

In principle, an arrangement according to the invention may be linked to one or more possibly different human/machine interfaces. In this case, it is expedient for provision to be made, among these human/machine interfaces, for at least one display, such that anomaly characteristic values and/or recommendations based on anomaly characteristic values with regard to operating the machine are able to be displayed.

One advantageous variant of the invention makes provision for the classifier to be designed as a supervised model (see also https://de.wikipedia.org/wiki/%C3%9Cberwachtes_Lernen), in particular operating in accordance with the nearest centroid or random forest method, or as a neural network.

One advantageous variant of the invention makes provision for a respective separate anomaly recognition model to be assigned to the individual operating-point clusters, in particular wherein a respective separate anomaly recognition model is assigned to each operating-point cluster. This architecture enables particularly efficient recognition of the anomalies, because the anomalies, as the invention has specifically observed, may generally occur in an operating-point cluster-specific manner. The classification into operating-point clusters, on the one hand, and the modeling of the anomaly recognition specifically for these clusters, makes the individual anomaly recognition models faster and more efficient than in the case of anomaly recognition without previous cluster formation. The separate assignment of an anomaly recognition model to a respective operating-point cluster concerns both the training phase and the application phase. In other words, the individual anomaly recognition models are preferably trained in an operating-point cluster-specific manner in the training phase, and then preferably applied in the anomaly recognition model in an operating-point cluster-specific manner in the application phase in order to recognize anomalies.

The invention furthermore relates to a computer program product for performing a method according to the description of the invention or exemplary embodiments or according to at least one or a combination of the claims by way of at least one computer. The computer program product may in this case be stored on a data carrier and be able to be transported, divested or used in some other way by way of this data carrier and/or by way of downloads from the data carrier.

The invention furthermore relates to an arrangement, in particular comprising at least one computer for performing a method according to at least one or a combination of the claims by way of at least one computer, wherein the arrangement comprises the at least one computer prepared to perform the method. For this purpose, the computer is preferably prepared, with a computer program product according to the invention, to carry out the method. The computer may also be a computer network, wherein the method may be applied by way of multiple computers that execute the method in parallel or together. As an alternative or in addition, the computer may be designed as an edge device, preferably arranged in the spatial environment or in the preferably direct vicinity of the machine or installed on the machine. The arrangement may preferably also comprise the machine, in particular a motor, for example an electric motor, in particular comprising an inverter.

According to one possible exemplary implementation of the invention, a machine, in particular a motor and the application data thereof, is monitored in an operating point-specific manner. The various operating points are in this case

automatically detected and grouped by way of clustering algorithms. An unsupervised model is then trained to carry out anomaly recognition for each operating point. Different variables (for example vibration, temperature, etc.) may thus be monitored within each detected operating point.
A supervised classifier is furthermore created based on the clustering results in order to classify the operating points during operation. Historical data in the form of fingerprints/reference measurements preferably form the basis for the creation.

A fingerprint is intended to be created at the beginning of the training phase of the possible exemplary implementation of the invention. The fingerprint is in this case a set of measurements from sensors (for example Siemens SIMOTICS CONNECT 400) or other data sources (for example motor digital twin) within a defined time range and describes the reference behavior or normal behavior of the motor application. The fingerprint in this case contains multiple operating points. This provided fingerprint is preprocessed, that is to say data cleansing and data scaling are performed, in order to obtain a usable standard. Other data sources may also be used for the preprocessing, for example motor nominal values that have been obtained from a digital twin of the motor.

In this exemplary implementation of the invention, the preprocessed data are then used as input for the clustering algorithm that is based on machine learning (here in particular preferably hierarchical clustering). The operating points are preferably clustered mainly on the basis of speed curves and torque curves in the fingerprint, but other values may also be used. The identified clusters are then used to train a tested classifier (for example nearest centroid or random forest classifier or one designed as a neural network) to classify new data in a cluster.

For each cluster, an anomaly recognition model based on one or more KPIs (for example vibration, temperature, etc.) is implemented.
The models are then stored in order to be applied later to new data.

An application phase of one exemplary implementation of the invention makes provision for the created models to be applied to new measurements in order to recognize anomalies. First of all, a new measurement is assigned to a specific operating point. The corresponding anomaly recognition model is then triggered and calculates an anomaly characteristic value or anomaly score that describes the severity of the anomaly. Based on the anomaly characteristic value, specific recommendations/activities may be triggered.
These models preferably recognize, even during operation, when a new measurement does not belong to a known operating point, that is to say the application is running at a new operating point. In this case, the method may make provision for the model in question or the models either to be automatically retrained or for a recommendation to be given via a human/machine interface to perform a training phase.

The advantages of the invention are in particular:
- early recognition of faults and anomalies in order to avoid unplanned stoppages and better planning of maintenance activities,
- efficiency in terms of maintenance and troubleshooting as a result of isolating the anomaly according to operating point,
- extending production by changing to a safe operating point and avoiding critical operating points,
- distinction between operation-related anomalies (for example blockages in the pump) and anomalies caused by increased vibrations (imbalance, misalignment, bearing damage, etc.).

The invention is described in more detail below with reference to one specific exemplary embodiment for explanatory purposes. In the figure:

figure 1 shows a schematic flowchart of the method according to the invention.

Figure 1 shows a schematic flowchart of the method PRC according to the invention for monitoring the operation of a machine MCH, here a motor ENG that is designed as an electrically driven motor EEG. A computer program product CPD according to the invention concerns the method PRC and is indicated schematically in figure 1, wherein the computer program product CPD is stored on a data memory and, when executed on at least one computer, prompts the computer to carry out the method. The method is accordingly computer-implemented. The computer and possibly the machine (for example comprising a motor) in this case corresponds to an arrangement ARR according to the invention.

A training phase TPH is first of all performed in multiple steps. In a step I., training data TDT comprising state variables PHC of multiple operating points OPP of the machine MCH are provided. The training data TDT comprise multiple operating points OPP and/or historical data and/or reference measurements and/or fingerprints.
Next, in a step II., operating points OPP of the training data TDT are recognized by way of clustering CLS and combined to form operating-point clusters OCL.
In a step III., a classifier CLF is trained to assign the operating points OPP to the recognized operating-point clusters OCL. The classifier CLF operates in accordance with the nearest centroid or random forest method.
In a step IV., anomaly recognition models ARM are trained to perform operating anomaly recognition.

The invention optionally makes provision for a respective separate anomaly recognition model ARM to be assigned to the individual operating-point clusters OCL, in particular wherein a respective separate anomaly recognition model ARM is assigned to each operating-point cluster OCL.

The training phase TPH is followed by an application phase APH. The application phase APH begins, in a step I., with the recording of operating data OPD comprising state variables PHC of operating points OPP of the machine MCH in a specific operating state. In this case, first of all, in a step II., the operating data OPD are assigned to the operating-point clusters OCL by way of the classifier CLF from the training phase TPH. The operating data OPD or operating points OPP comprise measured values of at least one of the following types: vibration, temperature, torque, pressure, current, voltage, power output. Next, in a step III., the at least one trained, preferably operating-point cluster-specific anomaly recognition model ARM recognizes operating anomalies ANM. The anomaly recognition model ARM is in this case an unsupervised model.

In a step PRP between steps I. and II., both of the training phase TPH and of the application phase APH (optionally also just one of the two phases), the training data TDT and/or operating data OPD are preprocessed by way of data cleansing and/or data scaling, in particular using further data sources and/or data from a digital twin and/or machine nominal values.

To classify a recognized operating anomaly ANM, the anomaly recognition model ARM calculates an anomaly characteristic value ASC. This value describes the severity of the anomaly. An operating anomaly ANM is recognized when the anomaly characteristic value ASC exceeds a predetermined threshold value ATH.

In a step IV., depending on the operating anomaly ANM:

- the anomaly characteristic value ASC and/or at least one recommendation RCM based on the anomaly characteristic value ASC with regard to operating the machine MCH are/is displayed, and/or
- the machine MCH is automatically controlled by way of a control command COD, such that the current operating point OPP of the machine MCH changes.

Patent claims

1. A method (PRC) for monitoring the operation of a machine (MCH), in particular of a motor (ENG) or electrically driven motor (EEG),
characterized by the following steps:

a) training phase (TPH):
   i. providing training data (TDT) comprising state variables (PHC) of multiple operating points (OPP) of the machine (MCH),
   ii. recognizing and combining operating points (OPP) of the training data (TDT) by way of clustering (CLS) to form operating-point clusters (OCL),
   iii. training a classifier (CLF) that assigns operating points (OPP) to the recognized operating-point clusters (OCL),
   iv. training at least one anomaly recognition model (ARM) to carry out operating anomaly recognition,

a) application phase (APH):
   i. recording operating data (OPD) comprising state variables (PHC) of operating points (OPP) of the machine (MCH) in an operating state,
   ii. assigning the operating data (OPD) to the operating-point clusters (OCL) by way of the classifier (CLF),
   iii. recognizing operating anomalies by way of the at least one anomaly recognition model (ARM).

2. The method (PRC) as claimed in claim 1, wherein the anomaly recognition model (ARM) is an unsupervised model.

3. The method (PRC) as claimed in claim 1 or 2, wherein operating points (OPP) and operating data (OPD) comprise measured values of at least one of the following types: vibration, temperature, torque, pressure, current, voltage, power output.

4. The method (PRC) as claimed in at least one of the preceding claims, wherein the training data (TDT) comprise multiple operating points (OPP) and/or historical data and/or reference measurements.

5. The method (PRC) as claimed in at least one of the preceding claims, comprising
- preprocessing the training data (TDT) and/or operating data (OPD) by way of data cleansing and/or data scaling, in particular using further data sources and/or data from a digital twin and/or machine nominal values.

6. The method (PRC) as claimed in at least one of the preceding claims, wherein the anomaly recognition model (ARM) calculates an anomaly characteristic value (ASC) the value of which describes the severity of the anomaly, wherein an anomaly and/or an anomaly type is recognized when the anomaly characteristic value (ASC) exceeds a predetermined threshold value (ATH).

7. The method (PRC) as claimed in at least one of the preceding claims, comprising:
- displaying the anomaly characteristic value (ASC) and/or recommendations (RCM) based on the anomaly characteristic value (ASC) with regard to operating the machine (MCH) and/or
- controlling, in particular automatically controlling the machine (MCH), such that the current operating point (OPP) of the machine (MCH) changes.

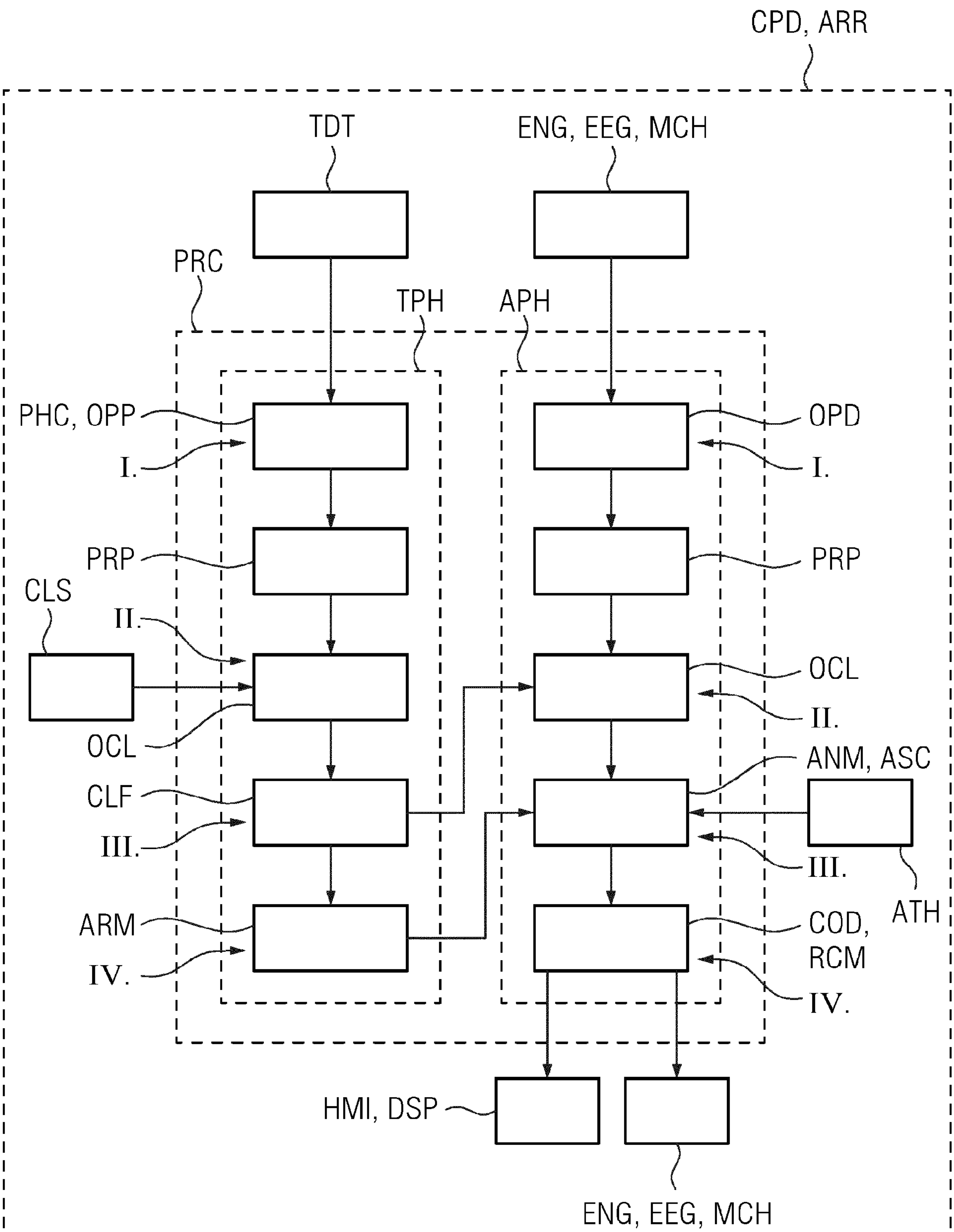
8. The method (PRC) as claimed in at least one of the preceding claims, wherein the classifier (CLF) is designed as a neural network or operates in accordance with the nearest centroid or random forest methods.

9. The method (PRC) as claimed in at least one of the preceding claims, wherein a respective separate anomaly recognition model

(ARM) is assigned to individual operating-point clusters (OCL), in particular wherein a respective separate anomaly recognition model (ARM) is assigned to each operating-point cluster (OCL).

10. A computer program product for performing a method as claimed in one of the preceding claims by way of at least one computer (CMP) or computer network.

11. An arrangement, in particular comprising at least one computer for performing a method as claimed in one of preceding claims 1 to 9 by way of at least one computer (CMP), wherein the arrangement comprises the at least one computer (CMP) prepared to perform the method.


CPD, ARR
TDT
ENG, EEG, MCH
PRC
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I.
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III.
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IV.
COD,
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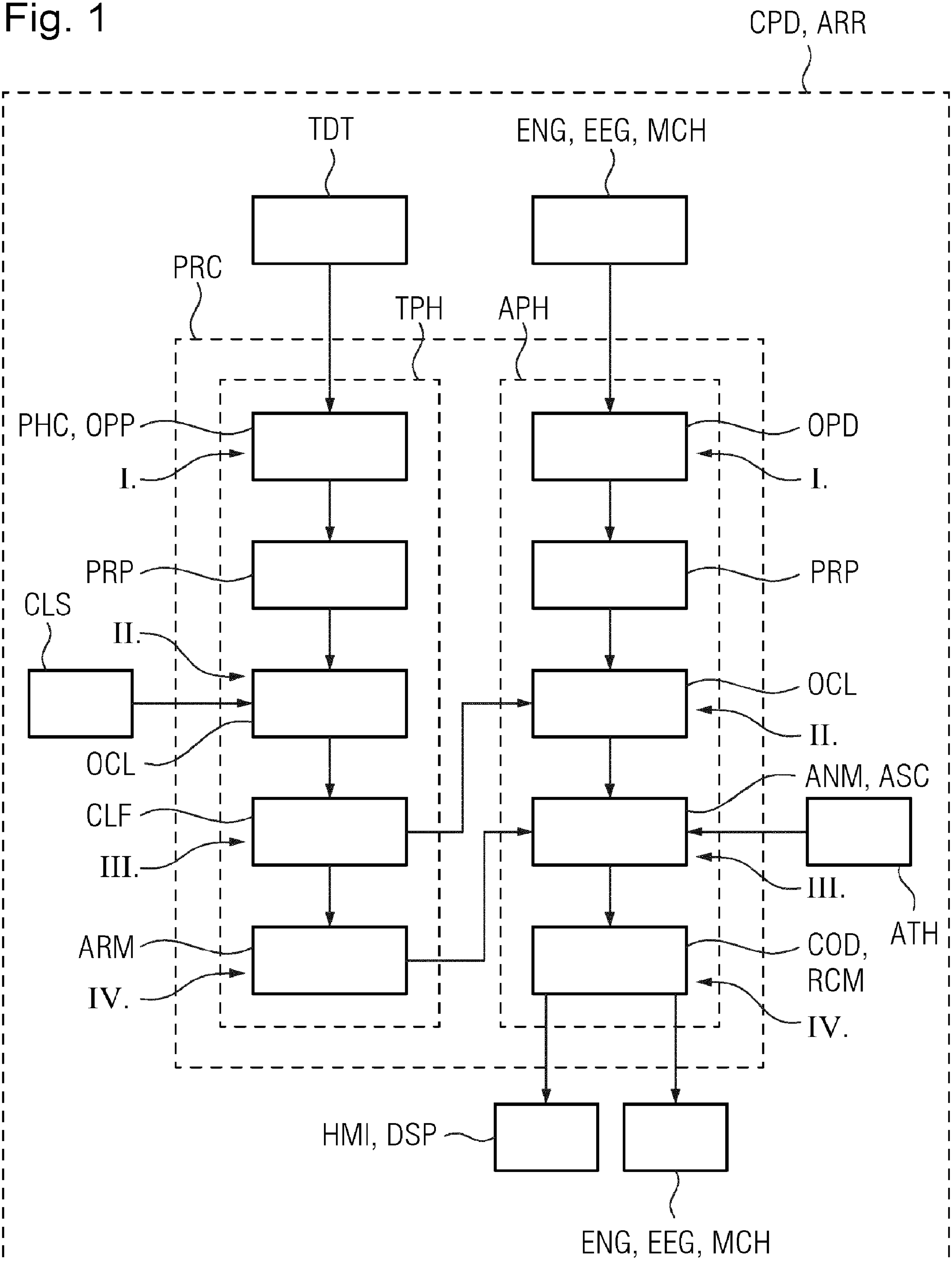
HMI, DSP
ENG, EEG, MCH

Fig. 1



CPD, ARR
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ENG, EEG, MCH