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(73) Patenthaver: **ALSTOM Holdings, 48 rue Albert Dhalenne, 93400 Saint-Ouen-sur-Seine, Frankrig**

(72) Opfinder: **STAINO, Andrea, , 78600 MAISONS LAFFITTE, Frankrig**
MIJATOVIC, Nenad, , 75015 PARIS, Frankrig
KAY, Fabien, , 95320 SAINT-LEU-LA-FORET, Frankrig
ROBERTS, John, , 78600 MAISONS LAFFITTE, Frankrig
CABOT, Julien, , 92210 SAINT CLOUD, Frankrig

(74) Fuldmægtig i Danmark: **Novagraaf Brevets, Bâtiment O2, 2 rue Sarah Bernhardt CS90017, F-92665 Asnières-sur-Seine cedex, Frankrig**

(54) Benævnelse: **FREMGANGSMÅDE TIL RANGORDNING AF KØRETØJER I EN FLÅDE AF KØRETØJER IFØLGE ET VEDLIGEHOLDELSESBEHOV; TILKNYTTET COMPUTERPROGRAM OG COMPUTERSYSTEM**

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METHOD FOR ORDERING VEHICLES OF A FLEET OF VEHICLES ACCORDING TO A MAINTENANCE REQUIREMENT; ASSOCIATED COMPUTER PROGRAM AND COMPUTER SYSTEM

Description

The field of the present invention is that of the maintenance of a fleet of vehicles, in particular of rail vehicles, such as trains, subway trains, streetcars, etc.

Systems for monitoring potential faults in rail vehicles, based on the generation of events during the operation of this vehicle, are known. More precisely, the monitored vehicle is equipped with a plurality of sensors capable of acquiring data which, once processed, allow characteristic events to be generated. An event is a new entry in a monitoring database. It is defined by a plurality of attributes, such as a vehicle identifier, an event identifier, an event occurrence time, the type of event, and various values characterizing it (which may depend on the type of event).

Currently, the events generated for a vehicle are analyzed by maintenance operators to diagnose the state of the vehicle and determine whether a maintenance operation needs to be carried out on this vehicle, and the nature of this maintenance operation: mere inspection or replacement of a particular component that is failing (or about to fail) on the rail vehicle in question.

However, such monitoring systems generate thousands of events every day for every vehicle in a fleet.

Such a load of information is difficult for a single operator to analyze. Such analysis remains complex, especially when it comes to establishing significant correlations between events. It therefore requires a significant investment in terms of working time and cost.

Additionally, it is virtually impossible for an operator to compare the vehicles in a fleet with one another to determine which of these vehicle is in urgent need of maintenance, in order to prioritize the maintenance operations required on that vehicle over another. At the moment, the decision to inspect one vehicle over another is essentially an empirical decision taken by the maintenance operator.

It would therefore be advantageous to be able to quickly and easily identify the one or more vehicles in a fleet that need priority maintenance, even if only to optimize maintenance tasks and limit the time for which an item of equipment cannot be used.

Document US 2019/197798 A1 presents a computer-implemented method for ordering the vehicles of a fleet of vehicles according to a need for maintenance, the method including the steps of, for each vehicle in the fleet, determining a time series, the time series including, for each time step, an instantaneous value of at least one quantity of interest obtained from monitoring events acquired by means of a system for monitoring vehicles of the fleet of vehicles; and, analyzing, over a predetermined time interval, the time series, taking into account the time series determined for all of the vehicles of the fleet of vehicles, considering that at each time step, the state of a vehicle is either a “normal” state or an “abnormal” state requiring maintenance, so as to obtain an optimal sequence of states over the predetermined time interval.

The object of the present invention is, in particular, to address this need.

To this end, the invention provides an alternative method, a computer program product and a computer system according to the accompanying claims.

The invention and its advantages will be better understood on reading the following detailed description of a particular embodiment, given solely by way of non-imitating example, this description being made with reference to the appended drawings in which:

[Fig. 1] figure 1 schematically shows a computer system for implementing the method according to the invention, and

[Fig. 2] figure 2 schematically shows, in the form of a block diagram, one preferred embodiment of the ordering method according to the invention.

The method according to the invention allows trains in a fleet of trains to be automatically ordered according to a need for maintenance.

A fleet of trains is made up of a plurality of similar or even identical trains, which are run on a network in an essentially interchangeable way. Put another way, ordering the trains in a fleet in relation to one another according to a need for maintenance makes sense because these various trains are alike in terms of structure (and therefore in terms of wear and tear and potential faults) and in terms of use (and therefore in terms of operating conditions).

The method according to the invention is based on burst detection by analyzing a time series of a quantity of interest, derived from the events generated by a monitoring system of the prior art.

In the context of the time series analysis of a quantity, burst detection is a technique that makes it possible to identify those values of this quantity which show a substantial increase over a limited period of time relative to a baseline level.

Numerous burst detection algorithms are known, particularly in signal processing applications. Generally speaking, a burst detection algorithm identifies periods of time (or bursts) during which a target value is unusually frequent.

Burst detection algorithms can be adapted for discrete data streams, as in the case of the events generated by a train fleet monitoring system. In the following, the embodiment presented in detail implements a burst detection algorithm based on a logarithmic maximum likelihood.

According to the invention, burst detection for a particular train is carried out by determining the baseline level from the events generated by the monitoring system for all of the trains in the fleet.

Fig. 1 shows a computer system 10 for implementing the method according to the invention.

It includes a monitoring database 12 that collects the events generated by a system 20 for monitoring the trains in a fleet.

The computer system 10 comprises a computer 14 including computing means, such as a processor, and storage means, such as a memory. The memory stores computer program instructions, in particular a program 30, the execution of which allows the method according to the invention to be implemented.

The program 30 can be broken down into modules, in particular a module 32 for determining a time series of a quantity of interest, a module 34 for time series analysis, a module 36 for burst detection, and a module 38 for ordering the trains in the fleet.

Advantageously, the computer system 10 includes a human-machine interface 16, for example a tablet, for displaying the results of the implementation of the method according to the invention to a maintenance operator.

With reference to Fig. 2, one preferred embodiment of a method for ordering the trains in a fleet of trains according to a need for maintenance is shown.

The method 100 is implemented independently of a prior step 90 of acquiring events.

The method 100 as such includes a step 110 of determining a time series of a quantity of interest or characteristic (this step corresponding to the execution of the module 32), a step 120 of analyzing a time series (this step corresponding to the execution of the module 34), a step 130 of burst detection (this step corresponding to the execution of the module 36) and a step 140 of ordering the trains in the fleet (this step corresponding to the execution of the module 38).

Acquisition step 90

This step, prior to implementation of the method according to the invention, is carried out in accordance with the prior art.

It is carried out by the monitoring system 20.

It consists in acquiring monitoring data for each train in the fleet and in creating events based on the acquired data.

The data are delivered by sensors on each train.

The events are associated with a particular train. They are dated. For example, the time step selected for dating the events is a day.

The events are recorded in the monitoring database 12.

It should be noted that a high number of occurrences of an event may be due to an actual fault in the item of equipment being monitored (the monitoring system may then continue to flag this fault until it is repaired). However, a high number of occurrences may also be due to an error in the design of the monitoring system itself, in particular the fault modeling that this system uses to generate monitoring events (and so the monitoring system flags the event multiple times).

Step 110 for determining a time series of a quantity of interest

The purpose of step 110 is to construct, for each train, a time series of a quantity of interest from the events contained in the monitoring database 12.

The quantity of interest is any time variable derived from all or some of the monitoring events that are associated with a train and which make it possible, by aggregating these monitoring events, to quantify the need for maintenance at each time step.

For example, a time window corresponding, for example, to one week of train operation is first defined.

The quantity of interest is then, for example, the total number of monitoring events generated for the train in question within the time window. The quantity of interest calculated in this way is dated, for example, with the last day of the time window used.

It is then simply a matter of repeating this operation by dragging the time window for the chosen time step (a day in this instance) to calculate a quantity of interest for each day a train is in operation.

The time series for a train then consists of the sequence of values of the quantity of interest for that train.

Such a time series is obtained for each of the trains in the fleet.

Alternatively, instead of the cumulative number of events, the quantity of interest could correspond to the cumulative number of events of a particular type (i.e. those associated with a specific fault or a specific train component). In another variant, instead of analyzing only a time series of one quantity of interest, the choice could be made to calculate different quantities of interest and track each of these quantities over time.

<u>Step 120 of analyzing a time series</u>

For each train in the fleet, this step consists in analyzing the time series of the quantity of interest obtained in step 110 by applying a burst detection algorithm, and then quantifying the need for maintenance on the train in question according to the bursts detected.

This step takes into account not only the time series associated with the train in question, but also the time series associated with the other trains in the fleet.

The burst detection algorithm more particularly used in the present embodiment is based on the model that, at each time step, a train can only be in two possible states: a nominal operating state ("normal state" hereinafter) and an operating state requiring maintenance ("abnormal state" hereinafter).

More precisely, assuming that the events follow a binomial distribution when the train is in the normal state and a binomial distribution (identical for the sake of simplicity of the present description) when the train is in the abnormal state, the burst detection algorithm aims to determine the sequence of states that best corresponds to the observations formed by the values of the time series of the quantity of interest over the time interval in question.

For example, a time interval of one week, subdivided into time steps of one day, is considered. Each time step of the interval is indexed with the integer t between 1 and T, where is the maximum number of time steps in the interval of interest (here T equals 7).

A fleet of N trains is considered. Each train is indexed with an integer j between 1 and N

The daily value of the characteristic quantity for train j on day t is denoted by: $g_j(t)$

The daily value of the total characteristic quantity for all of the trains in the fleet on day t is given by: $g_F(t) = \sum_{j=1}^{N} g_j\,(t)$

The integrated value of the characteristic quantity for train j over the time interval is given by: $G_j = \sum_{t=1}^{T} g_j\,(t)$

The integrated value of the total characteristic quantity for all of the trains in the fleet over the time interval is given by: $G_F = \sum_{t=1}^{T} g_F\,(t)$

The probability of the baseline level for train j, or reference probability, is defined by: $p_j^{ref} = G_j/G_F$

This reference probability is associated with the normal state for train j. It corresponds to the events that affect train j relative to all of the events that affect the trains in the fleet, over the time interval in question.

The associated burst probability for train j is then defined by: $p_j^{burst} = \alpha.\, p_j^{ref}$, where α is a proportionality constant.

This burst probability is associated with the abnormal state for train j.

The next step is to calculate a sequence of states s(t) over the time interval in question that is compatible with the characteristic values $g_j(t)$ and $g_F(t)$ for train j.

To do this, a statistical criterion is chosen. For example, in the present embodiment, the chosen statistical criterion is based on a cost function associating a logarithmic likelihood function, advantageously combined with a transition function.

The instantaneous likelihood function associated with the state s(t) at time t (also denoted by *s*) for train j is the binomial likelihood function $\mathcal{L}_{s,j}(t)$:

$$\mathcal{L}_{s,j}(t) = \binom{g_F(t)}{g_j(t)} \cdot p_j^s]^{g_j(t)}.\,[(1 - p_j^s)]^{g_F(t)-g_j(t)}$$

For numerical reasons, it is sought to minimize the logarithm of $\mathcal{L}_{s,j}(t)$ over the time interval in question. To evaluate the likelihood of the normal state (s = “normal”), the probability p_j^s is taken to be equal to p_j^{ref}. The likelihood of the abnormal state (s = “abnormal”) is evaluated by taking p_j^s to be equal to p_j^{burst}.

The transition function $H_{s,j}^{s'}(t)$ from the state *s* at time t to the state *s'* at the next time t+1 associates a cost with a change of state.

Preferably, since, by definition, the normal state is the expected state of the train and the abnormal state is an “exceptional” state, the transition function is non-zero only if there is a change of state and the transition is from the normal state to the abnormal state.

It is conceivable for the transition function to be proportional to T, to make it comparable with the likelihood term in the optimization process as T increases (i.e. as the time interval increases).

Thus, the instantaneous criterion to be minimized is:

$$f_j(t) = -ln\left(\mathcal{L}_{s,j}(t)\right) + H_{s,j}^{s'}(t)$$

Over the time interval, the criterion to be minimized becomes:

$$F_j = \sum_{t=1}^{T} f_j(t)$$

The optimal sequence of the states s(t) of train j, i.e. the sequence of the states (“normal” or “abnormal”) of train j that best explains the observation according to the binomial model, is therefore the one that minimizes the cost function for all of time steps in the time interval in question.

The optimal sequence is determined, for example, by optimization using a “greedy” algorithm as known to a person skilled in the art.

<u>Burst detection step 130</u>

Finally, the optimal sequence of states is analyzed to isolate any bursts therein. A burst is characterized by a minimum number of consecutive time steps in the abnormal state. This threshold number is predefined. It can be set to one, in which case a burst is detected as soon as the train is in the abnormal state.

In addition to its duration, a burst can be characterized by intensity. The intensity of a burst is, for example, given by the sum of the values of the cost function $f_j(t)$ over the one or more time steps associated with the burst.

Ordering step 140

Once the preceding steps have been completed for each train, the way in which the trains in the fleet are ordered depends on the quantity of interest.

If, as in the preceding example, the cumulative number of daily events is considered, then the trains can be ranked in descending order of the duration of the bursts detected for each train over the time interval in question. If two bursts have the same duration, then the trains are ranked by decreasing intensity of these bursts.

If, on the other hand, the number of daily events of a particular type is considered, then the bursts are ranked by intensity (bearing in mind that intensity takes into account the duration of the burst in a way).

Once the trains in the fleet have been ordered by priority, only the identifiers of the first X trains (e.g. X=3) are displayed on the interface 16.

Advantageously, by selecting the identifier of a train, the operator accesses the Y most recurrent events (for example, Y=5) affecting this train

Advantages

This method helps maintenance operators select the top-priority train for maintenance quickly and efficiently.

What is relevant for ranking trains with respect to one another is not the number of occurrences of events as such, but rather a significant change in the proportion of events generated by a train relative to the rest of the fleet, over a certain period of time and possibly for a certain type of event.

If an unusual and abrupt increase occurs for a particular train (in the total number of events, or only for a single type of event), then it can be considered that, for whatever reason, the behavior of this train has changed. It is important to flag this automatically, as it may be symptomatic of something abnormal that needs to be rectified as soon as possible.

PATENTKRAV

1. Computerimplementeret fremgangsmåde (100) til rangordning af køretøjerne i en flåde af køretøjer ifølge et behov for vedligeholdelse, hvilken fremgangsmåde, for hvert køretøj i flåden, indbefatter følgende trin:

- bestemmelse (110) af en tidsrække, hvor tidsrækken, for hvert tidstrin, indbefatter en momentan værdi for mindst én størrelse af interesse, opnået ud fra monitoreringsbegivenheder, der opnås ved hjælp af et system til monitorering af køretøjer i flåden af køretøjer; og

- analysering (120), i et forudbestemt tidsinterval, af tidsrækken, hvor der tages højde for den tidsrække, som er bestemt for alle køretøjerne i flåden af køretøjer, hvor det antages, at et køretøjs tilstand, på hvert tidstrin, er enten en "normal" tilstand eller en "unormal" tilstand, der kræver vedligeholdelse, med henblik på at opnå en optimal sekvens af tilstande i det forudbestemte tidsinterval,

hvor fremgangsmåden er **kendetegnet ved, at** den omfatter følgende yderligere trin:

- detektering (130), for hvert køretøj i flåden, af den eventuelle tilstedeværelse af én eller en flerhed af "bursts" i den optimale sekvens af tilstande; derefter

- rangordning (140) af en liste over køretøjer i flåden af køretøjer ifølge egenskaberne for de "bursts", der detekteres for hvert køretøj.

2. Fremgangsmåde ifølge krav 1, hvor størrelsen af interesse er det totale antal begivenheder eller det totale antal begivenheder af en bestemt type, der angår det pågældende køretøj, opnået i løbet af et referencetidsvindue.

3. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor analysering af tidsrækken indbefatter en optimering af en omkostningsfunktion, der forbinder en sandsynlighedsfunktion og præferentielt en overgangsfunktion, med henblik på at bestemme en momentan sandsynlighed for hvert tidstrin.

4. Fremgangsmåde ifølge krav 3, hvor den momentane sandsynlighed for et tidstrin sammenlignes med en referencesandsynlighed, der beregnes ud fra størrelserne af interesse for alle køretøjer i flåden af køretøjer, med henblik på at bestemme den optimale tilstand af det pågældende køretøj på det pågældende tidstrin.

5. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor detektering af tilstedeværelsen af "bursts" i den optimale sekvens af tilstande består af bestemmelse af et antal konsekutive tidstrin, hvor køretøjet befinder sig i den "unormale" tilstand i den optimale sekvens af tilstande, og antagelse, når antallet af tidstrin er større end en forudbestemt tærskelværdi, af, at det drejer sig om en "burst".

6. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor en "burst" er **kendetegnet ved** en varighed og/eller en intensitet, og rangordning af listen over køretøjer i flåden af køretøjer ifølge egenskaberne for de detekterede "bursts" for hvert køretøj udføres afhængigt af varigheden og/eller intensiteten af de pågældende bursts.

7. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor køretøjet er et jernbanekøretøj, såsom et tog, et undergrundstog eller en sporvogn.

8. Computerprogram, der indbefatter softwareinstruktioner, som ved afvikling med en computer implementerer en fremgangsmåde ifølge et hvilket som helst af de foregående krav.

9. Computersystem (10), **kendetegnet ved, at** det er egnet til implementering af en fremgangsmåde (100) ifølge et hvilket som helst af kravene 1 til 6, hvor computersystemet er egnet til at give adgang til indholdet i en monitoreringsdatabase (23) med henblik på læsning af monitoreringsbegivenheder, der er opnået ved hjælp af et monitoreringssystem (20).

10. System ifølge krav 9, der indbefatter:

- et modul (32) til bestemmelse af en tidsrække for en størrelse af interesse;

- et modul (34) til analysering af tidsrækken for en størrelse af interesse med henblik på at bestemme en optimal sekvens af tilstande;

- et modul (36) til detektering af "bursts" i den optimale sekvens af tilstande; og

- et modul (38) til skemalægning af køretøjerne i en flåde af køretøjer ifølge egenskaberne for de detekterede "bursts".

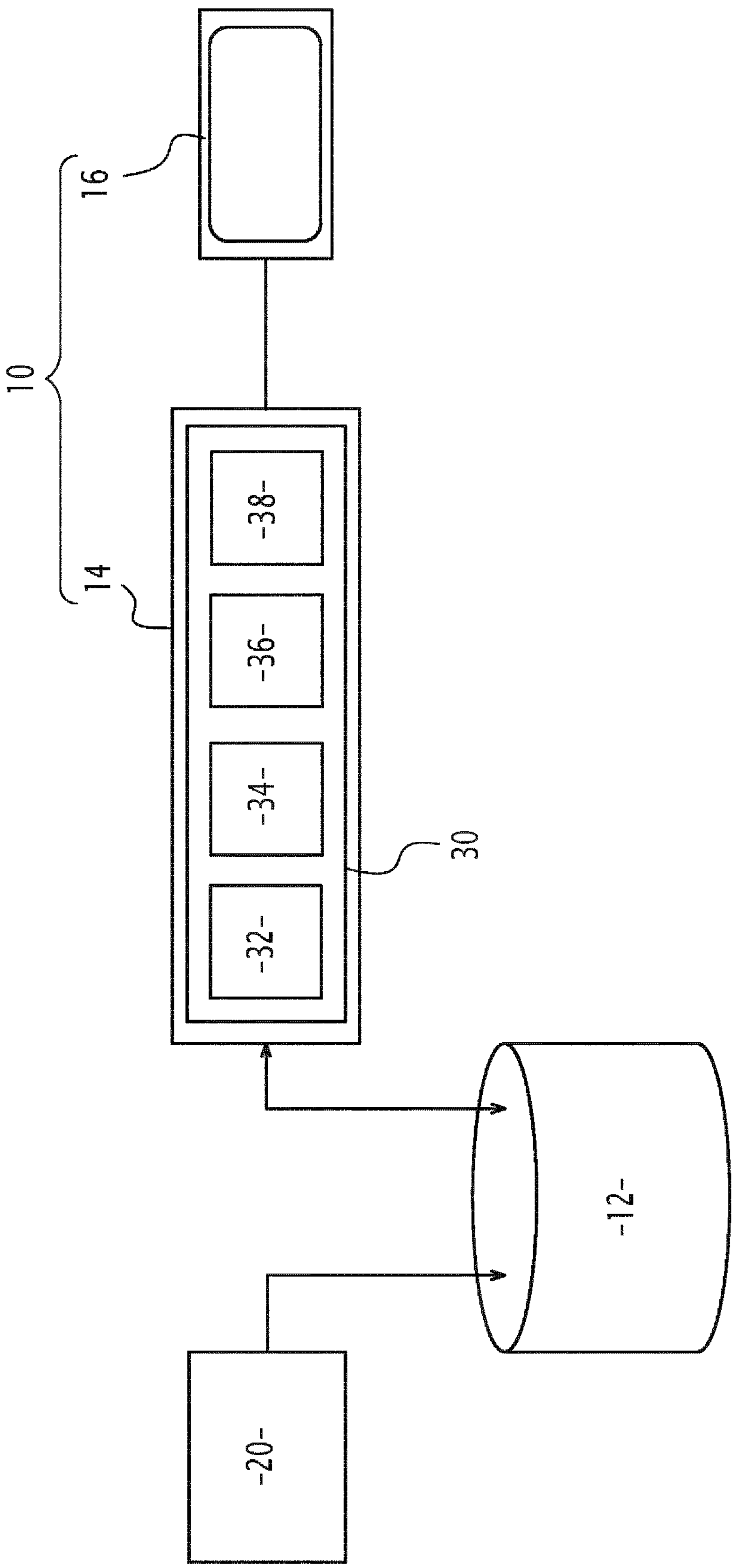

FIG.1

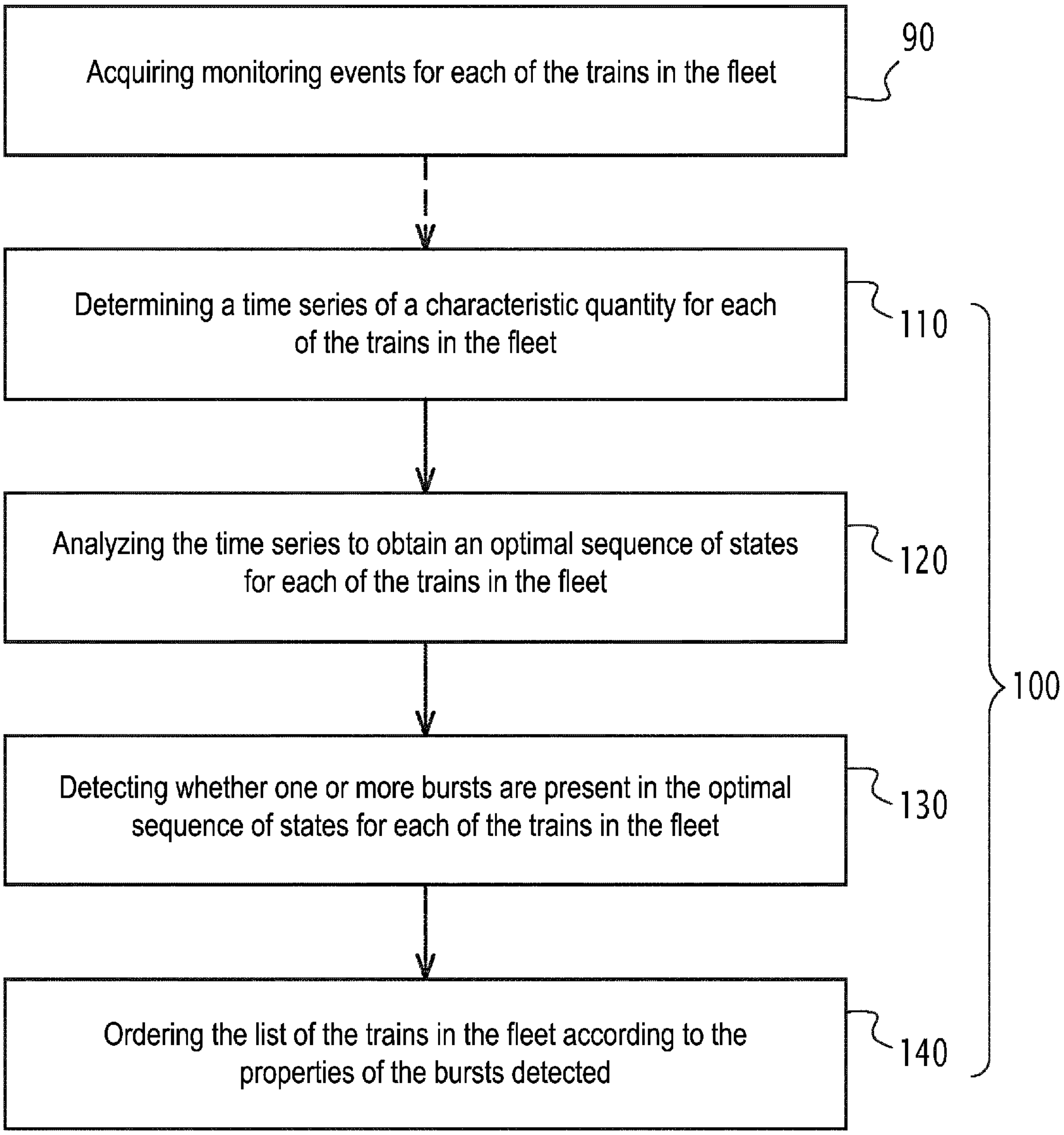
Acquiring monitoring events for each of the trains in the fleet
90
Determining a time series of a characteristic quantity for each of the trains in the fleet
110
Analyzing the time series to obtain an optimal sequence of states for each of the trains in the fleet
120
Detecting whether one or more bursts are present in the optimal sequence of states for each of the trains in the fleet
130
Ordering the list of the trains in the fleet according to the properties of the bursts detected
140
100

FIG.2