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(54) METHODS AND DEVICES FOR MONITORING TRAIN INTEGRITY

(57) A railroad train includes an integrity monitoring system with a three-axis inertial measurement unit. Incremental rotation values are measured along three reference axes during a plurality of measurement periods using the three-axis inertial measurement unit. A quaternion including first, second and third numerical values representative, respectively, of the measured incremental rotation values along the three reference axes is calculated for each measurement period. An anomalous variation of at least one of the first, second or third numerical values of the calculated quaternion is detected, said anomalous variation being representative of a train break-up condition.

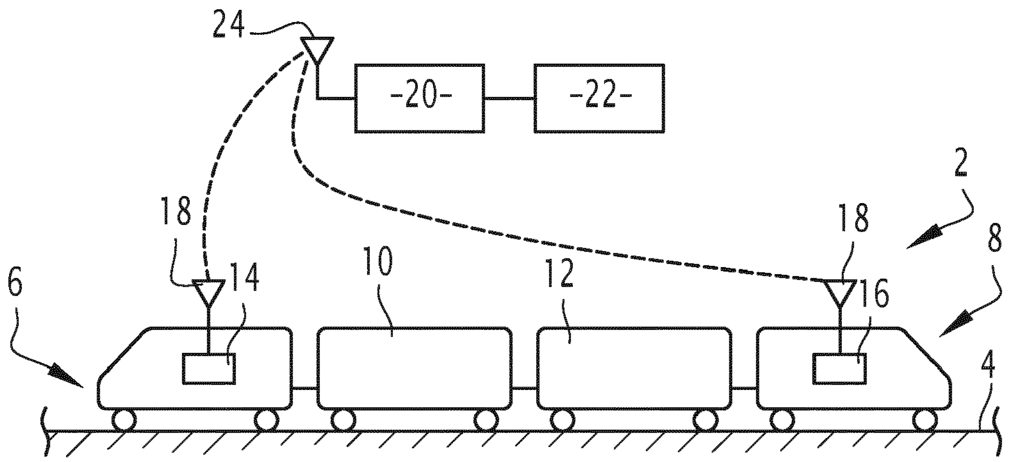

FIG.1

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to railroad technology and more generally to methods and devices for monitoring the integrity of a railroad vehicle.

BACKGROUND

[0002] Railroad vehicles are made up of several cars connected together by means of mechanical coupling devices. If a coupling device fails during operation, the railroad vehicle may break up accidentally. As a result, stray cars separated from the remainder of the vehicle are likely to run away uncontrollably on the railroad track and collide with other railroad vehicles.

[0003] To mitigate this risk, trackside monitoring devices such as axle counters have been used to detect any occurrence of a railroad vehicle break-up. For example, the number of axles of a train is counted upon entering and exiting a portion of a railroad track. An alert is raised if a discrepancy indicating a train breakup is detected.

[0004] However, with the advent of new railroad signaling systems, such as ERTMS Level 3, it is desirable to provide automated on-board methods and devices for monitoring train integrity.

SUMMARY

[0005] According to some aspects, a method for monitoring railroad vehicle integrity in a railroad vehicle including a three-axis inertial measurement unit placed in a rear portion of the railroad vehicle comprises:

measuring incremental rotation values along three reference axes of the railroad vehicle during measurement periods, using said three-axis inertial measurement unit,
detecting, by an electronic processing unit, any anomalous variation of at least one value representative of at least one of the measured incremental rotation values, said anomalous variation being representative of a railroad vehicle break-up condition.

[0006] In one or more embodiments, the method comprises:

calculating, by the electronic processing unit, advantageously for each measurement period, a quaternion including first, second and third numerical values representative of the measured incremental rotation values along the three reference axes,
and wherein detecting said anomalous variation includes detecting any anomalous variation of at least one of the first, second or third numerical values of the calculated quaternions, said anomalous variation being representative of a railroad vehicle break-up condition.

[0007] In one or more embodiments, detecting said anomalous variation includes detecting a change of sign of at least one of the first, second or third numerical values between two consecutive measurement periods.

[0008] In one or more embodiments, detecting said anomalous variation includes detecting an amplitude variation for at least one of the first, second or third numerical values higher than a predefined threshold over previous measurement periods.

[0009] In one or more embodiments, detecting said anomalous variation includes comparing at least one of the first, second or third numerical values for at least one measurement period with predefined reference data.

[0010] In one or more embodiments, the method further includes, upon identifying a break-up condition, estimating the railroad vehicle's location where the break-up took place, for example using a location device and/or using measured train speed and/or acceleration values.

[0011] In one or more embodiments, the first, second and third numerical values correspond respectively to incremental value motion amplitude along yaw, roll and pitch axes of the rolling stock vehicle in which the three-axis inertial measurement unit is located.

[0012] In one or more embodiments, the measurement periods are repeated with a sampling frequency comprised between 50Hz and 100Hz.

[0013] In one or more embodiments, the method includes, upon identifying a train break-up condition: sending an alarm signal to an external signaling system, such as a radio block center, using a radio transponder operatively coupled to the electronic processing unit.

[0014] According to other aspects, a railroad vehicle includes a three-axis inertial measurement unit placed in a rear portion of the railroad vehicle and an electronic processing unit programmed to perform steps of:

measuring incremental rotation values along three reference axes of the railroad vehicle during measurement periods using said three-axis inertial measurement unit,
detecting any anomalous variation of at least one value representative of at least one of the measured incremental rotation values, said anomalous variation being representative of a railroad vehicle break-up condition.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention will be better understood upon reading the following description, provided solely as an example, and made in reference to the appended drawings, in which:

- Fig. 1 is a simplified diagram of a railroad vehicle including a system for monitoring railroad vehicle integrity according to some embodiments;

- Fig. 2 is a simplified diagram of an exemplary system for monitoring railroad vehicle integrity according to some embodiments;
- Fig. 3 is a flow chart depicting an exemplary method for monitoring railroad vehicle integrity according to some embodiments.

DETAILED DESCRIPTION OF SOME EMBODIMENTS

[0016] Figure 1 illustrates a railroad vehicle such as a train 2 or a tramway or a metro running on a railroad track 4.

[0017] The train 2 comprises several railway/railroad cars also called rolling stock vehicles connected together by means of mechanical coupling devices, such as railroad couplers.

[0018] The rolling stock vehicles may be locomotives, or wagons or passenger cars, or motor coaches, or electric multiple units.

[0019] According to examples, the train 2 is a passenger train or a freight train.

[0020] In the illustrated example, the train 2 comprises a lead car 6, a rear car 8 and intermediary cars 10, 12 coupled together between the lead car 6 and the rear car 8.

[0021] In the above examples, the "lead" and "rear" ends of the train 2 may be defined in reference to the train's movement. For example, in reversible trains, the head and rear may be indistinguishable from each other and may be defined only in reference to the train's moving direction during operation.

[0022] In one or more embodiments, the train 2 also comprises a central control unit 14 adapted to implement and/or oversee signaling-related functions pertaining to the train 2.

[0023] In some examples, the central control unit 14 is an embodiment of the "European Vital Computer" (EVC) defined by ERTMS standards (European Rail Traffic Management System).

[0024] For example, the central control unit 14 includes electronic circuitry and/or at least one electronic processing unit such as a microprocessor, or a microcontroller, or a digital signal processing circuit, or an application-specific integrated circuit, or a programmable logic device, or any combination thereof.

[0025] The central control unit 14 may be programmed to automatically execute software instructions and/or software code stored in a computer memory (i.e., a non-transitory computer-readable storage medium) for implementing one or several algorithms.

[0026] According to some embodiments, the train 2 also comprises an onboard railway vehicle/train integrity monitoring system 16 including at least one three-axis inertial measurement unit and an electronic processing unit.

[0027] The integrity monitoring system 16 is configured to detect a break-up of the train 2 during operation, as explained below.

[0028] For example, a "train break-up" may be defined as an accidental separation of one or more of the rolling stock vehicles composing train 2, for example due to a failure of a mechanical coupling device. In practice, during such a break-up, one or more rolling stock vehicles are left on the tracks behind the remaining portion of the train 2 and are no longer under control of the train's driver.

[0029] In some embodiments, the control unit 14 and the monitoring system 16 both include a radio transponder 18 adapted to communicate wirelessly with a remote control center 20 through a radio communication link (illustrated on Figure 1 by dashed lines).

[0030] In the illustrated embodiments, the control unit 14 and the monitoring system 16 are embodied by two separate devices, which may be placed at different locations of the train 2.

[0031] Preferably, the monitoring system 16 is placed in a rear portion of the train, for example in the rear car 8. One reason is that, in practice, when a train break-up occurs, the stranded portion of train will correspond to the rear portion, while the front portion of the train (usually the one including the train's driver and at least one source of traction power) will continue to move ahead. Therefore, placing the monitoring system 16 in the rear of the train 2 will increase the chances of detecting a break-up event.

[0032] In the example above, the control unit 14 is placed in the lead car 6.

[0033] In some other embodiments, for example in reversible trains 2 or in trains 2 composed of electric multiple units, the integrity monitoring system 16 may be integrated into a control unit 14 (e.g., the electronic processing unit of the monitoring system 16 may be implemented by the control circuit 14).

[0034] In such cases, the train 2 may comprise two or more control units 14 each equipped with such integrity monitoring capabilities and placed at different locations of the train 2.

[0035] For example, control units 14 are placed in both lead and rear cars 6 and 8.

[0036] According to some embodiments, at least one radio block center (RBC) 20 is operatively coupled to a railroad control center 22.

[0037] For example, the radio block center 20 includes trackside signaling devices for controlling rail traffic in a specific area such as a railroad block, for example to acquire data related to block occupancy and to send railroad signals such as movement authority signals. The radio block center 20 may be automatically controlled by electronic circuitry and/or by relay-based electric circuits.

[0038] In some examples, the radio block center 20 includes a radio transponder 24 adapted to communicate wirelessly with the radio transponders 18.

[0039] The railroad control center 22, which may be part of a railroad interlocking facility, oversees rail traffic in a railroad network including one or more railroad blocks each controlled by a radio block center 20.

[0040] In the illustrated example, the control unit 14 may communicate with the remote radio block center 20 (and indirectly with the remote control center 22) using the radio communication link provided by radio transponders 18 and 24.

[0041] On Figure 2 there is illustrated a railway vehicle/train integrity monitoring system 30 installed onboard the train 2. The system 30 is an exemplary embodiment of the monitoring system 16 described above, however some features described below in reference to the system 30 may be applicable to other embodiments of the monitoring system 16.

[0042] According to some embodiments, the monitoring system 30 includes a three-axis inertial measurement unit 32 (such as a gyroscope or any appropriate motion sensor), a locating device 34, a speed sensor 36, an accelerometer 38 and an electronic processing unit 40. The radio transponder 18 is operatively coupled to the electronic processing unit 40.

[0043] In many examples, the electronic processing unit 40 includes electronic circuitry and/or at least one electronic processing unit such as a microprocessor, or a microcontroller, or a digital signal processing circuit, or an application-specific integrated circuit, or a programmable logic device, or any combination thereof.

[0044] The processing unit 40 may be programmed to automatically execute software instructions and/or software code stored in a computer memory (i.e., a non-transitory computer-readable storage medium) for implementing one or several algorithms.

[0045] The three-axis inertial measurement unit 32 is capable of measuring incremental rotation values of the rolling stock vehicle in which it is located (e.g., of the rear car 8).

[0046] For example, the three measurement axes of the inertial measurement unit 32 correspond to the pitch, yaw and roll axis of the car/rolling stock vehicle in which the measurement unit 32 is located.

[0047] The locating device 34 is adapted to determine geographic coordinates of the train 2.

[0048] In some embodiments, the locating device 34 includes a global satellite positioning device (e.g., a GPS receiver).

[0049] In some other embodiments, the locating device 34 is adapted to determine the train's location by using a beacon antenna belonging to a signaling system of the train 2 to identify the train's position relative to fixed signaling devices (such as trackside radio beacons). For example, the locating device 34 is implemented in software by using the processing unit 40 and/or includes special-purpose electronic circuitry.

[0050] For example, the train's position is located by the locating device 34 by identifying that the train lies in a specific block or a specific position of the railway (e.g., its position can be expressed relative to the known location of a trackside signal antenna or a beacon installed close to the railroad).

[0051] In other examples, the train's position may be identified by the locating device 34 by triangulation using radio signals exchanged with trackside signaling systems having a fixed known position.

[0052] In some other embodiments, the train's location may be estimated by measuring the train's speed and/or acceleration using the speed sensor 36 and/or the accelerometer 38 and then by computing, from the measured speed and/or acceleration values, the relative position of the train 2 with reference to a predefined location.

[0053] In some examples, the above methods for estimating the train's location may be combined, for example to obtain more reliable location information.

[0054] In some other examples, the locating device 34 and/or the speed sensor 36 and/or the accelerometer 38 may be omitted.

[0055] In some embodiments, the monitoring system 30 may be powered by a battery so as to be able to operate even when a break-up has occurred and the rear car 8 is separated from the train's 2 power source.

[0056] An exemplary method for monitoring train integrity using embodiments of the monitoring system 16 is now described in reference to the flow chart of Figure 3.

[0057] At step S100, incremental rotation values along three reference axes of the train are measured repeatedly, during a plurality of measurement periods, using the three-axis inertial measurement unit 32.

[0058] For example, the measurement periods are repeated with a sampling frequency comprised between 50Hz and 100Hz.

[0059] At step S102, a quaternion is calculated automatically, for each measurement period, using the processing unit 40.

[0060] For example, steps S102 are repeated regularly, preferably with the same frequency as steps S100.

[0061] Each quaternion includes first, second and third numerical values representative of the incremental rotation values measured along the three reference axes by the measurement unit 32 for the corresponding measurement period.

[0062] For example, a quaternion is a mathematical object comprising a vector value defined by first, second and third numerical values.

[0063] Advantageously, a quaternion is a mathematical object comprising a scalar value and a vector value defined by first, second and third numerical values.

[0064] In some embodiments, the quaternion defines rotation parameters using an axis-angle representation. The scalar value is representative of a rotation angle around a fixed axis (such as an Euler axis defined for this system). The first, second and third numerical values are representative of vector coordinates expressed relatively to unit vectors defining a fixed three-dimensional Cartesian reference frame.

[0065] Quaternions may be stored in memory and handled by the processing unit 40 as digital data structures, such as lists or vectors or any appropriate data structure.

[0066] If the rotation is sufficiently small (as is the case for incremental rotations measured by the measurement unit 32 during each of the measurement periods), then the scalar value can be approximated to take a null value and the first, second and third numerical values are representative of the incremental rotation motion undergone by the corresponding rolling stock vehicle/car during the measurement period.

[0067] In some embodiments, the first, second and third numerical values correspond to incremental value motion amplitude along yaw, roll and pitch axes of the rolling stock vehicle/car, such as the rear car 8 in which the three-axis inertial measurement unit 32 is located.

[0068] At step S104, the processing unit 40 automatically detects an anomalous variation of one of the first, second or third numerical values of the calculated quaternions, said anomalous variation being representative of a train break-up condition.

[0069] In some embodiments, detecting said anomalous variation includes detecting a change of sign of at least one of the first, second or third numerical values between two consecutive measurement periods.

[0070] For example, if a break-up occurs when the train 2 is climbing a slope, then the stray portion of train will suddenly run back down the slope and thus the pitch incremental rotation will suddenly change in the opposite direction.

[0071] In another example, if a break-up occurs when the train 2 is running along an inward curved portion of rail track, then the stray portion of train will suddenly reverse and follow an outward turning movement opposed to the previous inward turning movement. Thus, the yaw incremental rotation will suddenly change in the opposite direction.

[0072] In some embodiments, detecting said anomalous variation includes detecting an amplitude variation for at least one of the first, second or third numerical values higher than a predefined threshold over previous measurement periods.

[0073] For example, an anomalous variation is said to occur for one of said numerical values if the amplitude of said numerical value (i.e., the magnitude of change of the numerical value) varies (in absolute value) more than 20%, or more than 40%, or more than 60%, or more than 100%, over one or several measurement periods.

[0074] For example, if a break-up occurs when the train 2 is running down a slope, then the stray portion of train will suddenly run down the slope much faster (since the train's driver will no longer be able to control the brakes of the stray portion) and thus the magnitude of the pitch incremental rotation will suddenly increase while remaining in the same direction.

[0075] In some embodiments, detecting said anomalous variation includes comparing at least one of the first, second or third numerical values for at least one measurement period with predefined reference data.

[0076] Referring back to Figure 2, the monitoring system 30 may include a database 42 including quaternion-related reference data and/or a database 44 including train break-up reference data, which may be built beforehand using simulation data and/or experimental data and/or data acquired during previous train break-up incidents (reference 46).

[0077] For example, during step S104, the magnitude and/or pattern of change of at least one of the first, second or third numerical values (or any composite value representative of rotation angular change computed from said first, second or third numerical values) is compared with reference data from database 42 and/or from database 44.

[0078] According to other examples, the monitoring system 30 may automatically compute (e.g., extrapolate), between actual measurements, predicted first, second and third values, based on values of the most recently measured quaternion values and using reference data included in databases 42 and/or 44, such as geometrical features of the railroad track and/or dynamic response of the train 2.

[0079] Then, after a measurement has taken place (step S102), during the corresponding step S104, the calculated quaternion values are then compared with the predicted values and an anomalous variation is found is one or several of the first, second or third measured numerical values differ from the predicted values by more than a predefined threshold.

[0080] Optionally, relevant data may be chosen from databases 42 and/or 44 by the processing unit 40 depending on the estimated location of the train's 2.

[0081] In some other embodiments, the processing unit 40 may implement any combination of the exemplary detection methods described above.

[0082] In any case, according to many embodiments, if no anomalous variation is detected during step S104, then no break-up condition is identified. Train operation may continue normally and steps S100, S102 and S104 may continue to be repeated, possibly until the end of the train's journey.

[0083] However, if an anomalous variation is detected then, at step S106, a train break-up condition is automatically identified by the processing unit 40.

[0084] Optionally, the train's location may be estimated (and recorded) by the monitoring system 30 using the locating device 34 and/or the speed sensor 36 and/or the accelerometer 38 as previously described.

[0085] In response to the identification of train break-up condition, at step S108, an alarm signal is automatically sent by the monitoring device 16 to an external signaling system, such as the radio block center 20, using the radio transponder 18 associated to the monitoring system 16.

[0086] Optionally, the break-up location estimated by the monitoring system 30 is also sent to the signaling system alongside the alarm signal.

[0087] In some embodiments, upon receiving the alarm signal, the external signaling system automatically takes action to manage the situation according to predefined safety rules, for example by preventing incoming trains from colliding with the stray portion of the train 2 and/or by stopping the remainder of the train 2.

[0088] For example, the radio block center 20 may send a notification to the control center 22. The radio block center 20 (and possibly some neighboring radio block centers 20 controlled by the control center 22) may update the railroad signals under their control to stop all railroad traffic in the corresponding railroad portion, for example by updating the movement authority of the train 2 and/or of any other incoming train.

[0089] Optionally, the external signaling system may be requested to confirm occurrence of a break-up event before taking action such as updating signals.

[0090] For example, after step S106, the monitoring system 30 automatically sends measured rotation data to the external signaling system (e.g., to the radio block center 20) and the latter is programmed to automatically confirm or deny the occurrence of the break-up event, for example based on knowledge of features of the corresponding rail track (e.g., slope gradients, curvature, length, etc.).

[0091] In summary, the embodiments disclosed above advantageously provide automated methods and devices for monitoring train integrity using on-board equipment installed inside the train 2. In other words, a train break-up can be detected without having to rely on external track circuits or trackside monitoring devices such as axle counters. This is particularly useful for use on railroads equipped with new signaling systems which do not rely on track circuits, such as ERTMS Level 3.

[0092] The embodiments and alternatives described above may be combined with each other in order to generate new embodiments of the invention.

Claims

1. A method for monitoring a railroad vehicle integrity, the railroad vehicle (2) including a three-axis inertial measurement unit (32) placed in a rear portion of the railroad vehicle, the method comprising:

   measuring (S100) incremental rotation values along three reference axes of the railroad vehicle during measurement periods, using said three-axis inertial measurement unit,
   detecting (S106), by an electronic processing unit, any anomalous variation of at least one value representative of at least one of the measured incremental rotation values, said anomalous variation being representative of a railroad vehicle break-up condition.

2. The method of claim 1, wherein the method comprises:

   calculating (S102), by the electronic processing unit, advantageously for each measurement period, a quaternion including first, second and third numerical values representative of the measured incremental rotation values along the three reference axes,
   and wherein detecting said anomalous variation includes detecting any anomalous variation of at least one of the first, second or third numerical values of the calculated quaternions, said anomalous variation being representative of a railroad vehicle break-up condition.

3. The method according to claim 1 or claim 2, wherein detecting said anomalous variation includes detecting a change of sign of at least one of the first, second or third numerical values between two consecutive measurement periods.

4. The method according to any one of claim 1 to claim 3, wherein detecting said anomalous variation includes detecting an amplitude variation for at least one of the first, second or third numerical values higher than a predefined threshold over previous measurement periods.

5. The method according to any one of claim 1 to claim 4, wherein detecting said anomalous variation includes comparing at least one of the first, second or third numerical values for at least one measurement period with predefined reference data.

6. The method according to any one of claim 1 to claim 5, wherein the method further includes, upon identifying a break-up condition, estimating the railroad vehicle's location where the break-up took place, for example using a location device (34) and/or using measured railroad vehicle speed and/or acceleration values.

7. The method according to any one of claim 1 to claim 6, wherein the first, second and third numerical values correspond to incremental value motion amplitude along yaw, roll and pitch axes of a car of the railroad vehicle in which the three-axis inertial measurement unit is located.

8. The method according to claims 1 to 7, wherein the measurement periods are repeated with a sampling frequency comprised between 50Hz and 100Hz.

9. The method according to claims 1 to 8, wherein the method includes, upon identifying a railroad vehicle break-up condition: sending (S108) an alarm signal to an external signaling system, such as a radio block center (20), using a radio transponder (18) operatively coupled to the electronic processing unit.

10. A railroad vehicle (2), comprising a three-axis inertial measurement unit (32) placed in a rear portion of the railroad vehicle and an electronic processing unit (40) programmed to perform steps of:

measuring (S100) incremental rotation values along three reference axes of the railroad vehicle during measurement periods using said three-axis inertial measurement unit,
detecting (S106) any anomalous variation of at least one value representative of at least one of the measured incremental rotation values, said anomalous variation being representative of a railroad vehicle break-up condition.

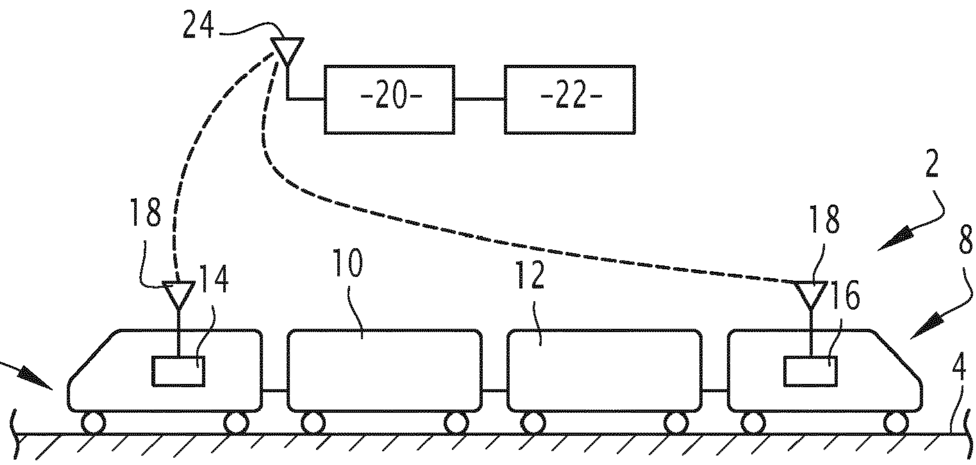

FIG.1

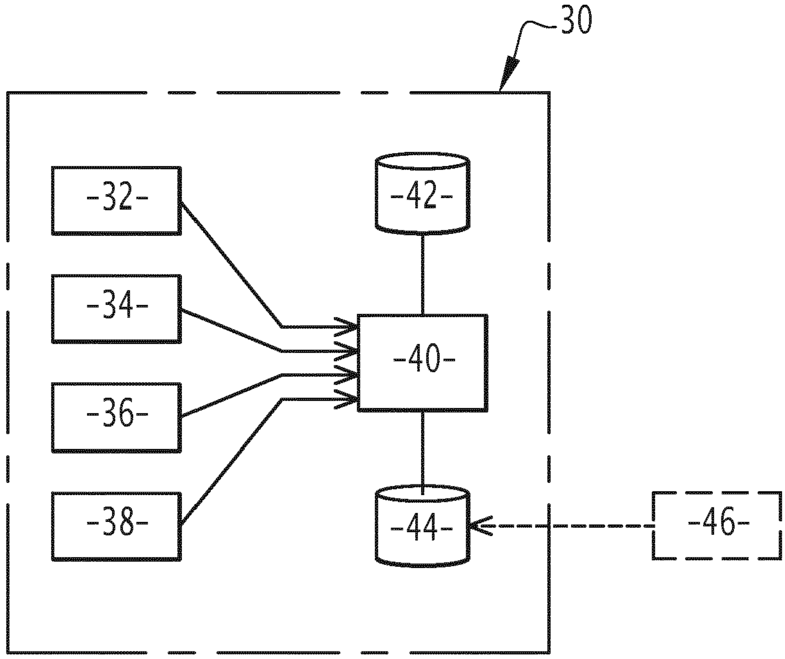

FIG.2

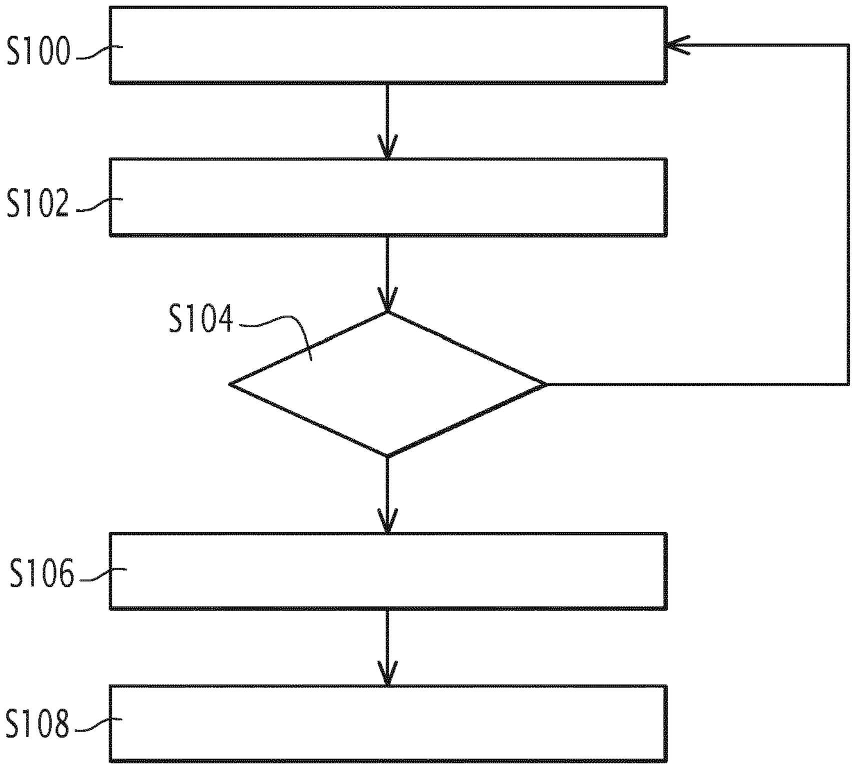

FIG.3

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EUROPEAN SEARCH REPORT

Application Number
EP 20 15 3910

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 2018 117478 A (RAILWAY TECHNICAL RES INST; KYOSAN ELECTRIC MFG) 26 July 2018 (2018-07-26) * figures 1 - 6; paragraphs [0001], [0045] and [0046] *	1-10	INV. B61L15/00 B61L27/00 B61L25/02
A	DE 10 2004 057545 A1 (ALCATEL SA [FR]) 8 June 2006 (2006-06-08) * paragraphs [0018], [0025] and [0026] *	1-10	
A	EP 2 944 537 A1 (BOMBARDIER TRANSP GMBH [DE]) 18 November 2015 (2015-11-18) * figure 1; paragraph [0047] *	1-10	

TECHNICAL FIELDS SEARCHED (IPC)
B61L

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	18 June 2020	Plützer, Stefan

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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18-06-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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