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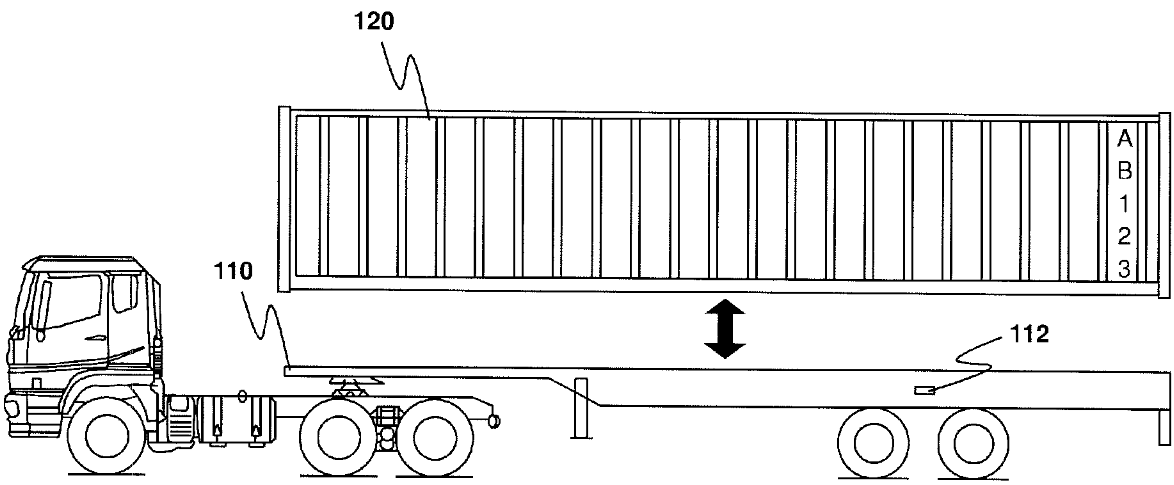

FIG. 1

(57) Abrégé/Abstract:
A method at a sensor apparatus affixed to a transportation asset, the method including detecting a trigger at the sensor apparatus; taking a threshold number of samples of a displacement-related value of the transportation asset over time; determining that a variance of the threshold number of samples exceeds a threshold; analyzing a frequency property based on the threshold number of samples; and based on the frequency property, determining whether the transportation asset is loaded or unloaded.

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Abstract

A method at a sensor apparatus affixed to a transportation asset, the method including detecting a trigger at the sensor apparatus; taking a threshold number of samples of a displacement-related value of the transportation asset over time; determining that a variance of the threshold number of samples exceeds a threshold; analyzing a frequency property based on the threshold number of samples; and based on the frequency property, determining whether the transportation asset is loaded or unloaded.

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METHOD AND SYSTEM FOR CARGO LOADING DETECTION

FIELD OF THE DISCLOSURE

[0001] The present disclosure relates to the transportation of goods, and in particular relates to cargo load detection of trailer chasses for the transportation of goods.

BACKGROUND

[0002] During the transportation of goods, determining whether a trailer is loaded is an important aspect of trailer asset management. With the transportation of shipping containers using tractor trailers, it is important to understand whether a trailer, referred to herein as a chassis, is loaded or not.

[0003] The information on vehicle loading may be beneficial to the transportation company. In particular, a transportation company managing a fleet of vehicles needs to know which vehicles are loaded and which vehicles are empty.

[0004] Typically, vehicle loading is determined by manual inspection, which is a cumbersome process that can be slow and inaccurate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The present disclosure will be better understood with reference to the drawings, in which:

[0006] Figure 1 is a side elevational view of a trailer chassis adapted to receive shipping containers, the figure showing an example placement of a sensor apparatus;

[0007] Figure 2 is block diagram of an example sensor apparatus capable of being used between embodiments of the present disclosure;

[0008] Figure 3 is a block diagram showing an example architecture for the sensor apparatus of **Figure 2**;

[0009] Figure 4 is a block diagram showing a container and chassis acting on a spring and damper;

[0010] Figure 5 is a plot showing the vibration magnitude as a function of frequency for a loaded and an unloaded chassis;

[0011] Figure 6 is a process diagram showing a process to determine whether a chassis is loaded or unloaded utilizing two bandpass filters;

[0012] Figure 7 is a process diagram showing a trigger process for starting and analysis on whether a chassis is loaded or unloaded;

[0013] Figure 8 is a block diagram showing an example infinite impulse response bandpass filter;

[0014] Figure 9 is a process diagram showing a frequency domain analysis of sensor readings to determine whether a chassis is loaded or unloaded;

[0015] Figure 10 is a plot showing frequency responses of the bandpass filters utilized in a practical test utilizing the process of **Figure 6**; and

[0016] Figure 11 is a block diagram of an example computing device or server capable of being used with the embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE DRAWINGS

[0017] The present disclosure provides a method at a sensor apparatus affixed to a transportation asset, the method comprising: detecting a trigger at the sensor apparatus; taking a threshold number of samples of a displacement-related value of the transportation asset over time; determining that a variance of the threshold number of samples exceeds a threshold; analyzing a frequency property based on the threshold number of samples; and based on the frequency property, determining whether the transportation asset is loaded or unloaded.

[0018] The present disclosure further provides a sensor apparatus affixed to a transportation asset, the sensor apparatus comprising: a processor; and a communications subsystem, wherein the sensor apparatus is configured to: detect a trigger at the sensor apparatus; take a threshold number of samples of a displacement-related value of the transportation asset over time; determine that a variance of the threshold number of samples exceeds a threshold; analyze a frequency property based on the threshold number of samples; and based on the frequency property, determine whether the transportation asset is loaded or unloaded.

[0019] The present disclosure further provides a computer readable medium for storing instruction code, which, when executed by a processor of sensor apparatus affixed to a transportation asset cause the sensor apparatus to: detect a trigger at the sensor apparatus; take a threshold number of samples of a displacement-related value of the transportation asset over time; determine that a variance of the threshold number of samples exceeds a threshold; analyze a frequency property based on the threshold number of samples; and based on the frequency property, determine whether the transportation asset is loaded or unloaded.

[0020] In accordance with the embodiments described below, cargo load detection systems utilizing a vertical accelerometer and/or strain gauges are described.

[0021] In the embodiments described below, the load detection is performed on a trailer chassis which is connected to a tractor. However, in other cases, the measurements may be made on other shipping containers, including, but not limited to, railcars, trucks, automobiles, among others.

[0022] In order to perform load detection, a sensor apparatus may be affixed to a container, trailer, or other similar asset. Such sensor apparatus may be mounted inside of a chassis of a flatbed trailer configured to receive shipping containers. Reference is now made to **Figure 1**.

[0023] In the embodiment of **Figure 1**, example truck trailer **110** is shown. In one embodiment, the computing device may be mounted within the chassis of the trailer. For example, in one embodiment the computing device may be mounted above the rear wheels of the truck trailer **110**. This is shown, for example, with sensor apparatus **112** in the embodiment of **Figure 1**.

[0024] However, in other cases it may be beneficial to have a different position for the sensor apparatus. Further, in some embodiments it may be useful to have a plurality of such sensor apparatuses within the trailer **110**.

[0025] The sensor apparatuses within trailer **110** may be used alone in some embodiments, or may be combined into sets of two or more sensor apparatuses and/or external sensors for load determination calculations.

[0026] In the embodiment of **Figure 1**, trailer **110** is adapted to secure and carry a shipping container **120** thereon. Information on whether the shipping container **120** is present or not would be useful to a transportation company.

[0027] ***Apparatus***

[0028] One sensor apparatus for a vehicle, chassis, trailer, container, or other transportation asset is shown with regard to **Figure 2**. The sensor apparatus of **Figure 2** is however merely an example and other sensing devices could equally be used in accordance with the embodiments of the present disclosure.

[0029] Reference is now made to **Figure 2**, which shows an example sensor apparatus **210**. Sensor apparatus **210** can be any computing device or network node. Such sensor apparatus or network node may include any type of electronic device, including but not limited to, mobile devices such as smartphones or cellular telephones. Examples can further include fixed or mobile devices, such as internet of things (IoT) devices, endpoints, home automation devices, medical equipment in hospital or home environments, inventory tracking devices, environmental monitoring devices, energy management devices, infrastructure management devices, vehicles or devices for vehicles, fixed electronic devices, among others.

[0030] Sensor apparatus **210** comprises a processor **220** and at least one communications subsystem **230**, where the processor **220** and communications subsystem **230** cooperate to perform the methods of the embodiments described herein. Communications subsystem **230** may, in some embodiments, comprise multiple subsystems, for example for different radio technologies.

[0031] Communications subsystem **230** allows sensor apparatus **210** to communicate with other devices or network elements. Communications subsystem **230** may use one or more of a variety of communications types, including but not limited to cellular, satellite, Bluetooth™, Bluetooth™ Low Energy, Wi-Fi, wireless local area network (WLAN), sub-giga hertz radios, near field communications (NFC), IEEE 802.15, wired connections such as Ethernet or fiber, among other options.

[0032] As such, a communications subsystem **230** for wireless communications will typically have one or more receivers and transmitters, as well as associated components such as one or more antenna elements, local oscillators (LOs), and may include a processing module such as a digital signal processor (DSP) or System on Chip (SOC). As will be apparent to those skilled in the field of communications, the particular design of the communication subsystem **230** will be dependent upon the communication network or communication technology on which the sensor apparatus is intended to operate.

[0033] Processor **220** generally controls the overall operation of the sensor apparatus **210** and is configured to execute programmable logic, which may be stored, along with data, using memory **240**. Memory **240** can be any tangible, non-transitory computer readable storage medium, including DRAM, Flash, optical (e.g., CD, DVD, etc.), magnetic (e.g., tape), flash drive, hard drive, or other memory known in the art.

[0034] Alternatively, or in addition to memory **240**, sensor apparatus **210** may access data or programmable logic from an external storage medium (not shown), for example through communications subsystem **230**.

[0035] In the embodiment of **Figure 2**, sensor apparatus **210** may utilize a plurality of sensors, which may either be part of sensor apparatus **210** in some embodiments or may communicate with sensor apparatus **210** in other embodiments. For internal sensors, processor **220** may receive input from a sensor subsystem **250**.

[0036] Examples of sensors in the embodiment of **Figure 2** include a positioning sensor **251**, a vibration sensor **252**, a temperature sensor **253**, one or more image sensors / cameras **254**, accelerometer **255**, light sensors **256**, gyroscopic sensors **257**, a door sensor **258**, a strain gauge **259**, and other sensors **260**. Other sensors may be any sensor that is capable of reading or obtaining data that may be useful for the sensor apparatus **210**. However, the sensors shown in the embodiment of **Figure 2** are merely examples, and in other embodiments, different sensors or a subset of sensors shown in **Figure 2** may be used. For example, in some cases the only sensor may be an accelerometer or a strain gauge.

[0037] Further, accelerometer **255** would typically provide acceleration sensors in three dimensions. Thus, accelerometer **255** would generally include three individual accelerometers. The readings from each of the three individual accelerometers could be isolated.

[0038] Communications between the various elements of sensor apparatus **210** may be through an internal bus **265** in one embodiment. However, other forms of communication are possible.

[0039] In the embodiment of **Figure 2**, rather than an internal strain gauge sensor **259**, in some cases the strain guage sensor may be external to the sensor apparatus and may be controlled by sensor apparatus **210**. Strain gauge sensor **270** may, for example, be mounted together with sensor apparatus **210** or may form part of sensor apparatus **210**. A single or multiple strain gauge sensors can be mounted on the longitudinal frame of the chassis to detect displacement when a container is loaded on the chassis. The strain gauge sensor may, in some embodiments, consist of a microprocessor, a strain gauge, a battery, and a short-range technology radio transmitter (Bluetooth, IEEE 802.15.4, or Wi-Fi). The sensor **270** could be configured to measure vertical displacement, or both vertical and horizontal displacement relative to the chassis.

[0040] The sensor apparatus **210** may communicate with the strain gauge sensor **270** or strain gauge **259** to query the strain gauge reading under a trigger condition. Examples of trigger conditions could be: on a regular wake-up schedule negotiated between the sensor(s) and the radar unit; when the trailer is in motion; and/or when the trailer stops, among other options.

[0041] A strain gauge will typically be displaced when the container is loaded and could be calibrated to estimate the relative or absolute weight of the container.

[0042] Sensor apparatus **210** may be affixed to any fixed or portable platform. For example, sensor apparatus **210** may be affixed to shipping containers or truck trailers in one embodiment. In other embodiments, sensor apparatus **210** may be affixed to a chassis of a trailer, as for example shown in **Figure 1**. In other cases, the sensor apparatus **210** may be affixed to any transportation asset for which load detection is needed, including self-propelled vehicles (e.g., automobiles, cars, trucks, buses, etc.), railed vehicles (e.g., trains and trams, etc.), and other types of vehicles including any combinations of any of the foregoing, whether currently existing or after arising, among others.

[0043] In other cases, sensor apparatus **210** may be part of a container that could be carried on or within a vehicle, for example container **120** from **Figure 1**. In accordance with the present disclosure, the term container may include any sort of cargo or item transportation such as vehicles, intermodal containers, shipping bins, lock boxes, and other similar vessels.

[0044] Such a sensor apparatus **210** may be a power limited device. For example, sensor apparatus **210** could be a battery-operated device that can be affixed to a shipping container or trailer in some embodiments. Other limited power sources could include any limited power supply, such as a small generator or dynamo, a fuel cell, solar power, energy harvesting, among other options.

[0045] In other embodiments, sensor apparatus **210** may utilize external power, for example from the battery or power system of a tractor pulling the trailer, via a wiring harness connected to a 7-pin plug, from a land power source for example on a plugged-in recreational vehicle or from a building power supply, among other options. Thus, the sensor apparatus **210** may also be connected to a power cord that receives its power from a power source.

[0046] External power may further allow for recharging of batteries to allow the sensor apparatus **210** to then operate in a power limited mode again. Recharging methods may also include other power sources, such as, but not limited to, solar, electromagnetic, acoustic or vibration charging.

[0047] The sensor apparatus from **Figure 2** may be used in a variety of environments. One example environment in which the sensor apparatus may be used is shown with regard to **Figure 3**.

[0048] Referring to **Figure 3**, three sensor apparatuses, namely sensor apparatus **310**, sensor apparatus **312**, and sensor apparatus **314** are provided.

[0049] In the example of **Figure 3**, sensor apparatus **310** may communicate through a cellular base station **320** or through an access point **322**. Access point **322** may be any wireless communication access point.

[0050] Further, in some embodiments, sensor apparatus **310** could communicate through a wired access point such as Ethernet or fiber, among other options.

[0051] The communication may then proceed over a wide area network such as Internet **330** and proceed to servers **340** or **342**.

[0052] Similarly, sensor apparatus **312** and sensor apparatus **314** may communicate with server **340** or server **342** through one or both of the base station **320** or access point **322**, among other options for such communication.

[0053] In other embodiments, any one of sensor apparatuses **310**, **312** or **314** may communicate through satellite communication technology. This, for example, may be useful if the sensor apparatus is travelling to areas that are outside of cellular coverage or access point coverage.

[0054] In other embodiments, sensor apparatus **312** may be out of range of access point **322**, and may communicate with sensor apparatus **310** to allow sensor apparatus **310** to act as a relay for communications.

[0055] Communication between sensor apparatus **310** and server **340** may be one directional or bidirectional. Thus, in one embodiment sensor apparatus **310** may provide information to server **340** but server **340** does not respond. In other cases, server **340** may issue commands to sensor apparatus **310** but data may be stored internally on sensor apparatus **310** until the sensor apparatus arrives at a particular location, possibly during a particular time window. In other cases, two-way communication may exist between sensor apparatus **310** and server **340**.

[0056] A server, central server, processing service, endpoint, Uniform Resource Identifier (URI), Uniform Resource Locator (URL), back-end, and/or processing system may be used interchangeably in the descriptions herein. The server functionality typically represents data processing/reporting that are not closely tied to the location of sensor apparatuses **310**, **312**, **314**, etc. For example, the server may be located essentially anywhere so long as it has network access to communicate with sensor apparatuses **310**, **312**, **314**, etc.

[0057] Server **340** may, for example, be a fleet management centralized monitoring station. In this case, server **340** may receive information from a sensor apparatus associated with various trailers or cargo containers, providing information such as the location of such cargo containers, the temperature within such cargo containers, any unusual events including sudden decelerations, temperature warnings when the temperature is either too high or too low, cargo loading within the trailer, the mass of the trailer, among other data. The server **340** may compile such information and store it for future reference.

[0058] Other examples of functionality for server **340** are possible.

[0059] In the embodiment of **Figure 3**, servers **340** and **342** may further have access to third-party information or information from other servers within the network. For example, a data services provider **350** may provide information to server **340**. Similarly, a data repository or database **360** may also provide information to server **340**.

[0060] For example, data services provider **350** may be a subscription-based service used by server **340** to obtain current road and weather conditions, or may be an inventory control system in some cases.

[0061] Data repository or database **360** may for example provide information such as image data associated with a particular location, aerial maps, detailed street maps, or other such information.

[0062] The types of information provided by data service provider **350** or the data repository or database **360** is not limited to the above examples and the information provided could be any data useful to server **340**.

[0063] In some embodiments, information from data service provider **350** or the data repository from database **360** can be provided to one or more of sensor apparatuses **310**, **312**, or **314** for processing at those sensor apparatuses.

[0064] A sensor apparatus such as that described in **Figures 2** and **3** above may be used to detect trailer loading of a container or trailer.

[0065] ***Calculating Trailer Loading***

[0066] In accordance with some embodiments of the present disclosure, the rear segment of a transportation vehicle or trailer can be modelled as a simple spring with a mass “m” representing the mass of the container and the mass of the chassis, and a spring constant “k”, where k is the stiffness of the structure and suspension. Further, a damper which may be dependent on the suspension of the chassis is represented with a damping constant “c”. For example, reference is now made to **Figure 4**.

[0067] In the embodiment of **Figure 4**, a container **410** has a mass “m_1”. A chassis **412** has a mass “m_2”. In the present disclosure, a mass “m” is the combination of masses m_1 and m_2.

[0068] A spring **420** is shown having a spring constant “k”, which is representative of the stiffness of the structure and suspension.

[0069] Further, the damping constant "c" is shown using a representation **422** of the suspension.

[0070] A displacement "h" shows the amount of motion of the chassis from the rest position of the chassis towards the ground, for example when a bump is encountered by the chassis while the vehicle is operating.

[0071] The equation describing the motion of the chassis in one-dimension, using a single spring-damper, can be expressed as provided in equation 1 below:

$$m\frac{d^2h}{dt^2} = -kh - c\frac{dh}{dt} \qquad (1)$$

[0072] In equation 1, m is the mass of the system, h is the displacement of the chassis from a rest position, t is time, k is the spring constant and c is the damping constant.

[0073] Solving equation 1 for the frequency of vibration yields equation 2:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}\sqrt{1-\left(\frac{c}{2\sqrt{mk}}\right)^2} \qquad (2)$$

[0074] Based on equation 2, the frequency of vibration is inversely proportional to the mass applied to the trailer. When the trailer is under the same moving conditions, the vibration frequency of the trailer will shift lower when a shipping container is loaded on the chassis.

[0075] If a truck, trailer or other similar asset is loaded within safe operating limits, the springs on the axles should not experience any significant deformations, which may affect the frequency of vibration.

[0076] The amplitude of the oscillations depends on the forces of any impacts between the wheels in the ground, but do not affect the frequency of vibration.

[0077] For example, reference is now made to **Figure 5**, which shows an example plot of the vibration frequencies seen when a chassis is loaded or unloaded with a shipping container, respectively. As seen from **Figure 5**, the frequency of the vibration shifts when the chassis is loaded.

[0078] Based on **Figure 5**, by measuring the frequency of vibration as observed by an accelerometer in the vertical direction and/or by a strain gauge, a detection of whether the chassis or trailer is loaded can be made.

[0079] ***Using Bandpass Filters***

[0080] For example, one option for making a determination on whether a chassis has a container thereon is provided with regard to **Figure 6**. However, the process of **Figure 6** is merely provided for illustration, and changes to the process of **Figure 6** could be made having regard to the other embodiments of the present disclosure.

[0081] The process of **Figure 6** starts at block **610** and proceeds to block **612** in which a check is made to determine whether a trigger condition has been met. The trigger condition could be any number of events that would indicate to the sensor apparatus that a reading needs to be made with regard to whether or not a container is loaded on the chassis.

[0082] For example, in one case, the trigger could be a message from a network server indicating that a determination should be made. This may be sent automatically by the network element periodically or may be sent based on input from an operator or transportation manager.

[0083] In other cases, the trigger could be a determination by the sensor apparatus that the sensor apparatus is in motion. For example, reference is now made to **Figure 7**. In the embodiment of **Figure 7**, the process may receive input from an accelerometer on the sensor apparatus. In alternative embodiments, the input could be from a global positioning system or global navigation Satellite system sensor within or communicating with the sensor apparatus.

[0084] Upon receiving such input, the process could, at block **710**, read in a sample from the accelerometer.

[0085] The process may then proceed to block **712** in which a moving variance of the acceleration of the chassis may be calculated.

[0086] From block **712**, the process proceeds to block **720** in which a check is made to determine whether the moving variance calculated exceeds a threshold “t1”. The threshold at t1 may be configured at the time that the sensor apparatus is deployed or provisioned on the sensor apparatus in some cases.

[0087] If the moving variance does not exceed the threshold, the process may proceed back to block **710** in which readings from the accelerometer may continue to be made. Specifically, if the moving variance does not exceed the threshold, then it is unlikely that the transportation asset is moving and that therefore there is no trigger condition.

[0088] Conversely, if it is determined that the moving variance exceeds the threshold at block **720**, then the process proceeds to block **730** in which a trigger event may occur.

[0089] In other cases, the trigger event may be a combination of factors. For example, a determination that the vehicle is moving along with a time window may be used to create the trigger event. In this way, the trigger event is not met too frequently, thereby potentially draining the battery of the sensor apparatus less. The use of a combination of a time or signal event, along with a determination that the vehicle is moving, could be beneficial to ensure meaningful calculations can be made in the process of **Figure 6**.

[0090] Other trigger events could equally be used at block **612** and the present disclosure is not limited to any particular trigger event.

[0091] If no trigger event is detected, the process will continue to loop at block **612** until the trigger event or condition is met.

[0092] Once a trigger condition is satisfied, the process proceeds to block **620** in which various variables may be reset. For example, a counter “n” may be used to count the number of samples received, and this counter may be reset to zero.

[0093] Further, as provided below, various bandpass filters could be used to find the energy within a particular band of the frequency spectrum. A first bandpass filter is denoted BPF_1 and a second bandpass filter is denoted BPF_2. For each sample of x, the output of BPF_1 is denoted as y_1 and the output of BPF_2 is denoted as y_2. The accumulated sum of squared value (ASSV) of y_1 is denoted as E_1 and the ASSV of y_2 is denoted as E_2.

[0094] In this regard, the E_1 and E_2 values may be reset to zero at block **620**. Further, optionally a moving variance and/or the bandpass filters themselves may be reset.

[0095] The process then proceeds to block **622** in which a sample from an accelerometer or the strain gauge may be read. The acceleration measured may be reduced by subtracting the acceleration of gravity and that the moving variance may be updated based on the new sensor reading.

[0096] The bandpass filter outputs y_1 and y_2 may then be obtained.

[0097] Further, E_1 may be updated as $E_1 = E_1 + y_1^2$. E_2 may be updated as $E_2 = E_2 + y_2^2$.

[0098] The count of the samples may further be incremented, as shown at block **622** with n=n+1.

[0099] As will be appreciated by those in the art, using the calculation of block **622** allows for minimal use of memory resources at the sensor apparatus, since the raw data does not need to be stored.

[00100] From block **622**, the process proceeds to block **630** and checks whether the number of samples has met a minimum number of sample threshold, denoted as N in the embodiment of **Figure 6**. If not, the process proceeds back to block **622** to continue to collect samples.

[00101] Once the threshold number of samples has been taken, the process proceeds to block **640** in which a check is made to determine whether the moving variance exceeds a threshold t1. Similar to the discussion with regard to the moving variance in **Figure 7**, if the threshold at t1 has not been exceeded, then the process may determine that a vehicle is not moving. In this case, the process may proceed to block **642** in which an indication that no decision may be made about the load status of the vehicle is noted, and the process proceeds back to block **612** to wait for the next trigger.

[00102] In some embodiments, optionally an additional check may be performed, to check whether the moving variance is too large as exceeding a second threshold denoted by t2 (not shown). That is, if the moving variance exceeds t2, the process may proceed to block **642** in which an indication that no decision may be made about the load status of the vehicle is noted, and the process proceeds back to block **612** to wait for the next trigger.

[00103] Conversely, if the moving variance exceeds the threshold t1 and optionally does not exceed the threshold t2, then the process may proceed from block **640** to block **644** in which an energy ratio “eR” may be calculated. In particular, the energy ratio may be calculated with regard to equation 3 below.

$$eR = \frac{E_1}{E_1 + E_2} \quad (3)$$

[00104] From equation 3 above, the energy ratio compares the ASSV from the first bandpass filter to the total ASSV of both bandpass filters. As seen in **Figure 5** above, since the first bandpass filter allows to pass signal in a lower frequency band than a higher frequency band that the second bandpass filter allows to pass, the energy ratio is reflective of the ASSV of the lower frequency band compared to the combined ASSV of both bandpass filters.

[00105] From block **644**, the process proceeds to block **650** in which a check is made to determine whether the energy ratio is less than a threshold t3. The threshold t3 may be a value that is based on the particular type of chassis on which the sensor apparatus is mounted and may be provisioned to the sensor apparatus or may be determined through a calibration process as described below.

[00106] If the energy ratio is less than the threshold to t3, the process proceeds to block **652** in which decision is made at that the chassis is empty.

[00107] From block **652**, the process may proceed back to block **612** to wait for a further trigger condition.

[00108] Conversely, if the energy ratio is not less than a threshold t3, then the process proceeds to block **660** in which a check is made to determine whether the energy ratio is greater than a threshold t4. The value of the threshold t4 again may be determined based on the type of chassis, and may be provisioned at the sensor apparatus or determined through calibration in some cases.

[00109] If the energy ratio exceeds the threshold t4 then the process proceeds to block **662** in which a determination is made that that the chassis is loaded. The process then proceeds to block **612** to wait for the next trigger.

[00110] If the energy ratio does not exceed the threshold t4 then the process proceeds to block **664** in which no decision on the loading status of the chassis is made. For example, this may occur if the value of the energy ratio falls between the thresholds t3 and t4. This range may indicate that a definitive determination cannot be made.

[00111] From block **664**, the process proceeds back to block **612** to wait for the next trigger condition.

[00112] In practice, two 3^{rd} order infinite impulse response (IIR) Butterworth bandpass filters have been utilized. However, the present disclosure is not limited to this particular order and type of a filter, and other IIR filters such as Elliptic, Bessel, Chebyshev type I, or Chebyshev type II filters could be used, for example. In other cases, finite impulse response (FIR) filters could be used.

[00113] The use of the bandpass filter rather than a low-pass filter avoids calculating a DC component of the data sequence x and further avoids the normalization of an output y_2 from a low-pass filter.

[00114] One example structure of an IIR filter is shown with regard to **Figure 8**. In particular, in the embodiment of **Figure 8**, an input sequence $x(m)$ results in output sequence $y(m)$ using equation 4 below:

$$y(m) = b(1)x(m) + b(2)x(m-1) + b(3)x(m-2) + \cdots + b(n)x(m-n+1) - a(2)y(m-1) - a(3)y(m-2) - \cdots - a(n)y(m-n+1) \quad (4)$$

[00115] Equation 4 can be represented as:

$$y(m) = \sum_{k=1}^{n} b(k)x(m-k+1) - \sum_{k=2}^{n} a(k)y(m-k+1) \quad (5)$$

[00116] Which can be further simplified to:

$$y(m) = \boldsymbol{b}\hat{\boldsymbol{x}} - \boldsymbol{a}\hat{\boldsymbol{y}} \quad (6)$$

[00117] Where $\boldsymbol{a} = \{a(k)\}$ and $\boldsymbol{b} = \{b(k)\}$ are two sets of coefficients of the filter, $k = 1,2, \ldots, n, a(1) = 1$ and $\hat{\boldsymbol{x}}$ and $\hat{\boldsymbol{y}}$ are vectors:

$$\hat{\boldsymbol{x}} = [x(m)\ x(m-1)\ x(m-2) \ldots x(m-n+1)]^T \quad (7)$$

[00118] and:

$$\hat{\boldsymbol{y}} = [0\ y(m-1)\ y(m-2) \ldots\ y(m-n+1)]^T \quad (8)$$

[00119] In equation 7 and 8 above, T is the matrix transpose.

[00120] Using equations 4 to 8 above, **Figure 8** shows the general structure of the IIR filter. In particular, the input $x(m)$ is provided to both an adder **810** as $b(1)x(m)$, as well as a time delay **812**.

[00121] The output from the time delay **812** is provided to adder **814** as $b(2)x(m-1)$, and is further provided to time delay **816**. The output from time delay **816**, which is $b(3)x(m-2)$, is provided to adder **818**.

[00122] The process continues until the time delay at time n, shown at block **820**, provides its output $b(n)x(m-n+1)$ to adder **822**.

[00123] A feedback loop from output $y(m)$ is provided to a time delay **830**, where $a(1)=1$.

[00124] The output from time delay **830** is provided to adder **814** as $-a(2)y(m-1)$. The output $y(m-1)$ is also provided to a time delay **832**. The output from time delay **832** is provided it to adder **818** as $-a(3)y(m-2)$.

[00125] The process then continues until a time delay **840** is encountered, where the output from this time delay is provided to adder 820 to as $-a(n)y(m-n+1)$.

[00126] Further, the output from each adder is provided to the previous adder. In this way, the output of the BFP, $y(m)$, can be found.

[00127] Thus, the embodiments of **Figures 6** to **8** provide a way to find a ratio of the signal energy in a first frequency band compared with the signal energy in both frequency bands in order to make a decision on whether a chassis is loaded.

[00128] While the embodiments of **Figures 6** to **8** are provided with regards to a chassis, in other cases, the embodiment of **Figures 6** to **8** could equally be used with a closed or open trailer to determine whether a load is found within or on such trailer.

[00129] Further, while the embodiment of **Figure 6** describes all calculations occurring at the sensor apparatus, in some cases the computing may be better done at a server. In this case, various information from the sensors associated with sensor apparatus may be provided back to a server, which may then use defined threshold and filter values to make a determination on whether the chassis is loaded or not.

[00130] ***Frequency Response Calculation***

[00131] While the embodiment of **Figures 6** to **8** is done in the time domain, another possible option is to estimate whether a chassis has a load in the frequency domain. For example, a Fourier transform (FT) may be applied to a signal such as the accelerometer samples. The Fourier transform may then be used to find the frequency with a peak magnitude. An effective way to do this is to utilize the Fast Fourier Transform (FFT) algorithm.

[00132] Reference is now made to **Figure 9**. In the embodiment of **Figure 9** the process starts at block **910**. For example, the process may start based on a trigger condition being met. As described above with regard to **Figure 7**, the trigger condition can be one or a combination of factors, including time-based factors, signaling from network elements, and/or determinations that the vehicle is moving.

[00133] From block **910**, the process proceeds to block **912** in which N samples are read from a sensor such as an accelerometer or a strain gauge, where each sample is denoted as “x”. The samples may be denoted in accordance with equation 9 below.

$$\boldsymbol{x} = \{x_k\}, where\ k = 0, 1, \dots, N-1 \qquad (9)$$

[00134] The variance of $\boldsymbol{x}$ (denoted as xVar) may then be found.

[00135] The process then proceeds to block **914** in which a check is made to determine whether xVar is greater than a threshold “t1”. The threshold t1 may be found based on a calibration sequence or may be based on provisioning of the sensor apparatus. Therefore, blocks **912** and **914** make a determination on whether the vehicle is moving.

[00136] In some cases, the process of blocks **912** and **914** may be optional if the trigger condition that started the process at block **910** includes a determination that the vehicle is moving. In this case, the blocks may be substituted by a process in which a number of samples N is read.

[00137] From block **914**, the process proceeds to block **920** in which N values (denoted by $\boldsymbol{y}$) can be obtained by applying a Fourier Transform to $\boldsymbol{x}$. In particular, y is denoted in accordance with equation 10 below.

$$\boldsymbol{y} = \{y_k\}, where\ k = 0, 1, \dots, N-1 \qquad (10)$$

[00138] In equation 10, k from 0 to N/2 corresponds to the frequency from 0 Hz to $f_s/2$ Hz respectively, with f_s being the sampling frequency (or equivalently, sampling rate), while k from (N/2 +1) to (N-1) corresponds to negative frequencies which are out of the topic of this document.

[00139] While block **920** uses a Fast Fourier Transform, in other cases, the Fourier transform may be performed in other ways. Therefore, the present disclosure is not limited to using Fast Fourier Transforms.

[00140] From block **920**, the process proceeds to block **922** in which the peak frequency is found, denoted as F_{pk}. In general, the peak frequency is found by search for $|y(F_{pk})|$, such that $|y(F_{pk})|$ is the maximum among $\{y_k\}$ for $k_1 \le k \le k_2$, where $k_1 > 0$ and $k_2 < N/2$.

[00141] From block **922**, the process proceeds to block **930** in which a check is made to determine whether F_{pk} is less than a threshold “t3”. In block **930**, F_{pk} is also greater than a threshold equivalent to k_1 as specified above to block the DC component. The value for the threshold t3 may be based on provisioning to the sensor apparatus based on the type of trailer, vehicle or chassis that the sensor apparatus is affixed to, may be found through calibration, among other options.

[00142] If F_{pk} is less than the threshold t3 then the process proceeds to block **932** in which a determination is made that the chassis is loaded. From block **932**, the process proceeds back to block **910** in which the process may start over, for example when a trigger condition is met.

[00143] Conversely, if F_{pk} is greater than the threshold t3 then the process proceeds to block **940**. At block **940**, a check is made to determine whether F_{pk} is greater than a threshold “t4”. The value for the threshold t4 may be based on provisioning to the sensor apparatus based on the type of trailer, vehicle or chassis that the sensor apparatus is affixed to, may be found through calibration, among other options.

[00144] If F_{pk} is greater than the threshold t4 then the process proceeds to block **942** in which a determination is made that the chassis is empty. From block **942**, the process proceeds back to block **910** in which the process may start over, for example when a trigger condition is met.

[00145] If F_{pk} is neither less than the threshold t3 nor greater than the threshold t4 then the process proceeds to block **950** in which no decision on the loaded status of the chassis may be made. For example, this may occur if the peak is found between thresholds t3 and t4. From block **950**, the process proceeds back to block **910** in which the process may start over, for example when a trigger condition is met.

[00146] Therefore, based on **Figure 9**, the loaded status of the chassis may be found through an analysis of the peak frequency in the frequency domain.

[00147] While the embodiment of **Figure 9** is provided with regards to a chassis, in other cases, the embodiment of **Figure 9** could equally be used with a closed or open trailer to determine whether a load is found within or on such trailer.

[00148] Further, while the embodiment of **Figure 9** describes all calculations occurring at the sensor apparatus, in some cases the computing may be better done at a server. In this case, various information from the sensors associated with sensor apparatus may be provided back to a server, which may then use defined threshold values to make a determination on whether the chassis is loaded or not.

[00149] ***Calibration***

[00150] As indicated above, when a sensor apparatus is first installed on a chassis or container, the system may be calibrated to allow for load detection on the trailer.

[00151] In one example, a data set may exist at a server and the type of trailer or chassis may be input into the sensor apparatus. At this point, the sensor apparatus may be provisioned with the values for the filter and the thresholds for the embodiment of **Figure 6** or with the threshold values for the embodiment of **Figure 9**.

[00152] In an alternative embodiment, when first installed, or at some subsequent point, a calibration mode may be entered into at the sensor apparatus. For example, the calibration mode can be manually configured, for example by pressing a button or otherwise locally interacting with that the sensor apparatus, or based on a command from a remote server. Once in calibration mode, the chassis that the sensor apparatus is affixed to is caused to have a vertical impact. For example, in one embodiment the vertical impact may involve driving the vehicle over a drop to initiate the spring response. However, in other cases, the vertical impact may be experienced simply by driving the vehicle over a normal road.

[00153] During calibration, manual input on whether the chassis is loaded or unloaded may be provided to allow for the threshold values and/or the filter parameters to be set at the sensor apparatus.

[00154] In some cases, calibration mode may be entered multiple times, for example when the chassis is empty and when the chassis is loaded to obtain accurate values for the thresholds and/or the filter values.

[00155] Further, in some cases, the filter values and thresholds derived for that particular trailer or chassis could be provided back to a network element for storage for future deployment of sensor apparatuses on similar chasses.

[00156] ***Practical Example***

[00157] The embodiments of **Figures 6** to **8** above were tested on a chassis of trailer. With this practical testing at a sampling rate equal to 50 samples per second, it was designed such that the first bandpass filter had a lower cut-off frequency equal to 2 Hz and an upper cut-off frequency equal to 6.5 Hz. Correspondingly, the filter coefficients , ***a*** and ***b*** were calculated as:

$$\boldsymbol{a} = [1, -4.3755, 8.3673, -8.9674, 5.6906, -2.0274, 0.31743] \quad (11)$$

[00158] and

$$\boldsymbol{b} = [0.01382, 0, -0.04146, 0, 0.04146, 0, -0.01382] \quad (12)$$

[00159] The second bandpass filter had a lower cut-off frequency equal to 6.5 Hz and an upper cut-off frequency equal to 11 Hz. The coefficients for this second bandpass filter were calculated as:

$$\boldsymbol{a} = [1, -2.3078, 3.6859, -3.4937, 2.5284, -1.0693, 0.31743] \qquad (13)$$

[00160] and

$$\boldsymbol{b} = [0.01382, 0, -0.04146, 0, 0.04146, 0, -0.01382] \qquad (14)$$

[00161] Using the above coefficients, the process of **Figure 6** was implemented in which the number of samples N was set to 1024, the bandpass filter order was three, t1 was set to 1, t3 was set to 0.4, and t4 was set to 0.6.

[00162] Utilizing these values, the frequency responses of the two designed bandpass filters are shown with regard to **Figure 10**.

[00163] While the embodiment of **Figure 6** or **Figure 9** shows only one test, in other cases improvements in reliability could be achieved by performing the test a number of times. For example, if the three tests were done, if two of the tests preferred “loaded” and one prefers “unloaded”, the decision would be “loaded”.

[00164] In other cases, a final decision may be based on a combined energy ratio value for multiple tests, where the combined energy ratio is a weighted sum of multiple individual energy ratios obtained from multiple tests and where each weight is associated with an individual energy ratio.

[00165] In other cases, the loading status typically would not change back-and-forth repeatedly in a short period of time. Thus, if a sudden change in the decision occurs following a relatively long period with a stable status, more tests may be performed and no decision may be made until a reliable conclusion is obtained.

[00166] A server such as servers **340**, **342** or **350** may be any network node. For example, one simplified server that may perform the embodiments described above is provided with regards to **Figure 11.**

[00167] In **Figure 11**, server **1110** includes a processor **1120** and a communications subsystem **1130**, where the processor **1120** and communications subsystem **1130** cooperate to perform the methods of the embodiments described herein.

[00168] The processor **1120** is configured to execute programmable logic, which may be stored, along with data, on the server **1110**, and is shown in the example of **Figure 11** as memory **1140**. The memory **1140** can be any tangible, non-transitory computer readable storage medium, such as DRAM, Flash, optical (e.g., CD, DVD, etc.), magnetic (e.g., tape), flash drive, hard drive, or other memory known in the art. In one embodiment, processor **1120** may also be implemented entirely in hardware and not require any stored program to execute logic functions.

[00169] Alternatively, or in addition to the memory **1140**, the server **1110** may access data or programmable logic from an external storage medium, for example through the communications subsystem **1130**.

[00170] The communications subsystem **1130** allows the server **1110** to communicate with other devices or network elements.

[00171] Communications between the various elements of the server **1110** may be through an internal bus **1160** in one embodiment. However, other forms of communication are possible.

[00172] The embodiments described herein are examples of structures, systems or methods having elements corresponding to elements of the techniques of this application. This written description may enable those skilled in the art to make and use embodiments having alternative elements that likewise correspond to the elements of the techniques of this application. The intended scope of the techniques of this application thus includes other structures, systems or methods that do not differ from the techniques of this application as described herein, and further includes other structures, systems or methods with insubstantial differences from the techniques of this application as described herein.

[00173] While operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be employed. Moreover, the separation of various system components in the implementation descried above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a signal software product or packaged into multiple software products. In some cases, functions may be performed entirely in hardware and such a solution may be the functional equivalent of a software solution.

[00174] Also, techniques, systems, subsystems, and methods described and illustrated in the various implementations as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods. Other items shown or discussed as coupled or directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component, whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and may be made.

[00175] While the above detailed description has shown, described, and pointed out the fundamental novel features of the disclosure as applied to various implementations, it will be understood that various omissions, substitutions, and changes in the form and details of the system illustrated may be made by those skilled in the art. In addition, the order of method steps is not implied by the order they appear in the claims.

[00176] When messages are sent to/from an electronic device, such operations may not be immediate or from the server directly. They may be synchronously or asynchronously delivered, from a server or other computing system infrastructure supporting the devices/methods/systems described herein. The foregoing steps may include, in whole or in part, synchronous/asynchronous communications to/from the device/infrastructure. Moreover, communication from the electronic device may be to one or more endpoints on a network. These endpoints may be serviced by a server, a distributed computing system, a stream processor, etc. Content Delivery Networks (CDNs) may also provide communication to an electronic device. For example, rather than a typical server response, the server may also provision or indicate data for a content delivery network (CDN) to await download by the electronic device at a later time, such as a subsequent activity of electronic device. Thus, data may be sent directly from the server, or other infrastructure, such as a distributed infrastructure, or a CDN, as part of or separate from the system.

[00177] Typically, storage mediums can include any or some combination of the following: a semiconductor memory device such as a dynamic or static random access memory (a DRAM or SRAM), an erasable and programmable read-only memory (EPROM), an electrically erasable and programmable read-only memory (EEPROM) and flash memory; a magnetic disk such as a fixed, floppy and removable disk; another magnetic medium including tape; an optical medium such as a compact disk (CD) or a digital video disk (DVD); or another type of storage device. Note that the instructions discussed above can be provided on one computer-readable or machine-readable storage medium, or alternatively, can be provided on multiple computer-readable or machine-readable storage media distributed in a large system having possibly plural nodes. Such computer-readable or machine-readable storage medium or media is (are) considered to be part of an article (or article of manufacture). An article or article of manufacture can refer to any manufactured single component or multiple components. The storage medium or media can be located either in the machine running the machine-readable instructions, or located at a remote site from which machine-readable instructions can be downloaded over a network for execution.

[00178] In the foregoing description, numerous details are set forth to provide an understanding of the subject disclosed herein. However, implementations may be practiced without some of these details. Other implementations may include modifications and variations from the details discussed above. It is intended that the appended claims cover such modifications and variations.

CLAIMS

1. A method at a sensor apparatus affixed to a transportation asset, the method comprising:

detecting a trigger at the sensor apparatus;

taking a threshold number of samples of a displacement-related value of the transportation asset over time;

determining that a variance of the threshold number of samples exceeds a threshold;

analyzing a frequency property based on the threshold number of samples; and

based on the frequency property, determining whether the transportation asset is loaded or unloaded.

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

determining a first bandpass filter output;

determining a second bandpass filter output, the second bandpass filter having a higher frequency band than the first bandpass filter;

determining an accumulated sum of squared value for the first bandpass filter output;

determining an accumulated sum of squared value for the second bandpass filter output; and

finding an energy ratio of the accumulated sum of squared value for the first bandpass filter output over the combined accumulated sum of squared value for the first and second bandpass filter outputs.

3. The method of claim 2, wherein the determining whether the transportation asset is loaded or unloaded comprises:

finding that the transportation asset is unloaded when the energy ratio is less than a second threshold; and finding that the transportation asset is loaded when the energy ratio is greater than a third threshold.

4. The method of claim 3, further comprising finding that a loaded status of the transportation asset is not available when the energy ratio is between the second threshold and the third threshold.

5. The method of claim 1, wherein the analyzing the frequency property comprises:

finding a frequency domain representation for the threshold number of samples; and

determining a peak frequency value within the frequency domain.

6. The method of claim 5, wherein the determining whether the transportation asset is loaded or unloaded comprises:

finding that the transportation asset is loaded when the peak frequency is less than a fourth threshold; and

finding that the transportation asset is unloaded when the peak frequency is less than a fifth threshold.

7. The method of claim 6, further comprising finding that a loaded status of the transportation asset is not available when the peak frequency is between the fourth threshold and the fifth threshold.

8. The method of claim 1, further comprising, prior to detecting the trigger:

entering into a calibration mode on the sensor apparatus;

operating the transportation asset in an unloaded state;

operating the transportation asset in a loaded state;

determining thresholds and values for the analyzing the frequency property.

9. The method of claim 1, wherein the trigger condition is a signal from a network element.

10. The method of claim 1, wherein the variance is a moving variance calculated as each sample is taken to reduce storage at the sensor apparatus.

11. The method of claim 1, wherein the displacement-related value is obtained from one or both of an accelerometer and a strain gauge.

12. A sensor apparatus affixed to a transportation asset, the sensor apparatus comprising:

a processor; and

a communications subsystem,

wherein the sensor apparatus is configured to:

detect a trigger at the sensor apparatus;

take a threshold number of samples of a displacement-related value of the transportation asset over time;

determine that a variance of the threshold number of samples exceeds a threshold;

analyze a frequency property based on the threshold number of samples; and

based on the frequency property, determine whether the transportation asset is loaded or unloaded.

13. The sensor apparatus of claim 12, wherein the sensor apparatus is configured to analyze the frequency property by:

determining a first bandpass filter output;

determining a second bandpass filter output, the second bandpass filter having a higher frequency band than the first bandpass filter;

determining an accumulated sum of squared value for the first bandpass filter output;

determining an accumulated sum of squared value for the second bandpass filter output; and

finding an energy ratio of the accumulated sum of squared value for the first bandpass filter output over the combined accumulated sum of squared value for the first and second bandpass filter outputs.

14. The sensor apparatus of claim 13, wherein the determining whether the transportation asset is loaded or unloaded comprises:

finding that the transportation asset is unloaded when the energy ratio is less than a second threshold; and

finding that the transportation asset is loaded when the energy ratio is greater than a third threshold.

15. The sensor apparatus of claim 14, wherein the sensor apparatus is further configured to find that a loaded status of the transportation asset is not available when the energy ratio is between the second threshold and the third threshold.

16. The sensor apparatus of claim 12, wherein the sensor apparatus is configured to analyze the frequency property by:

finding a frequency domain representation for the threshold number of samples; and

determining a peak frequency value within the frequency domain.

17. The sensor apparatus of claim 16, wherein the determining whether the transportation asset is loaded or unloaded comprises:

finding that the transportation asset is loaded when the peak frequency is less than a fourth threshold; and

finding that the transportation asset is unloaded when the peak frequency is less than a fifth threshold.

18. The sensor apparatus of claim 17, wherein the sensor apparatus is further configured to find that a loaded status of the transportation asset is not available when the peak frequency is between the fourth threshold and the fifth threshold.

19. The sensor apparatus of claim 12, wherein the sensor apparatus is further configured to, prior to detecting the trigger:

enter into a calibration mode on the sensor apparatus;

operate the transportation asset in an unloaded state;

operate the transportation asset in a loaded state; and

determine thresholds and values for the analyzing the frequency property.

20. The sensor apparatus of claim 12, wherein the trigger condition is a signal from a network element.

21. The sensor apparatus of claim 12, wherein the variance is a moving variance calculated as each sample is taken to reduce storage at the sensor apparatus.

22. The sensor apparatus of claim 12, wherein the displacement-related value is obtained from one or both of an accelerometer and a strain gauge.

23. A computer readable medium for storing instruction code, which, when executed by a processor of sensor apparatus affixed to a transportation asset cause the sensor apparatus to:

detect a trigger at the sensor apparatus;

take a threshold number of samples of a displacement-related value of the transportation asset over time;

determine that a variance of the threshold number of samples exceeds a threshold;

analyze a frequency property based on the threshold number of samples; and based on the frequency property, determine whether the transportation asset is loaded or unloaded.

1/11

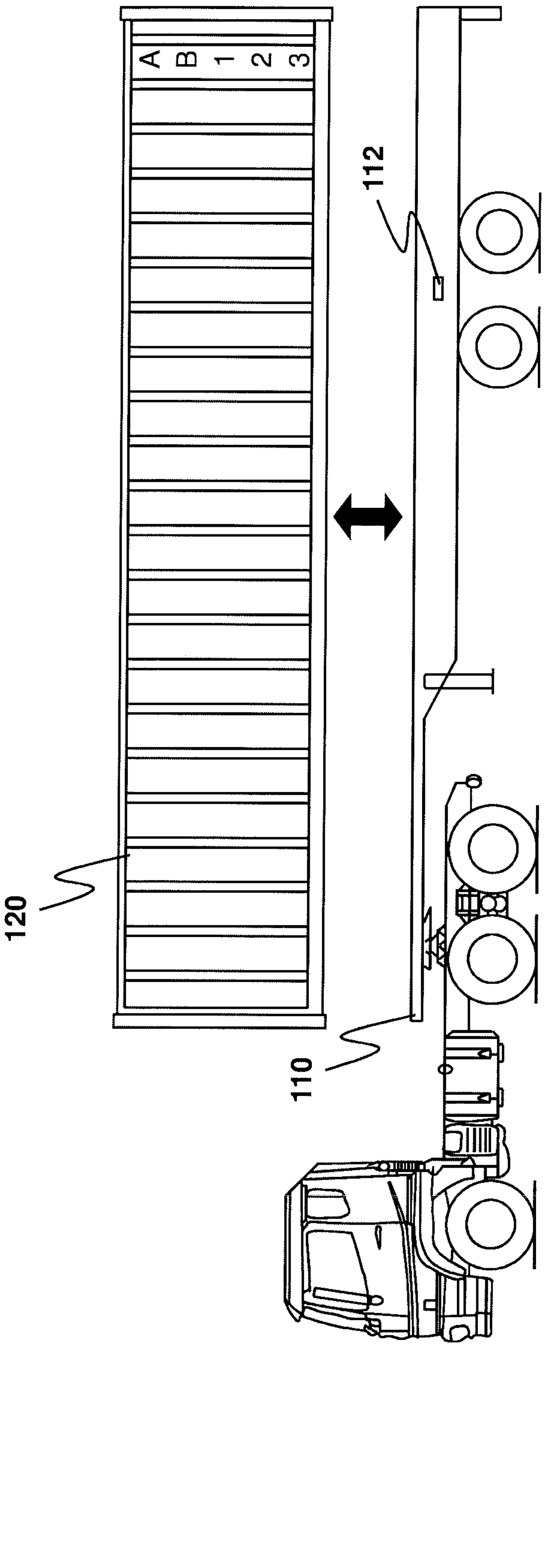


FIG. 1

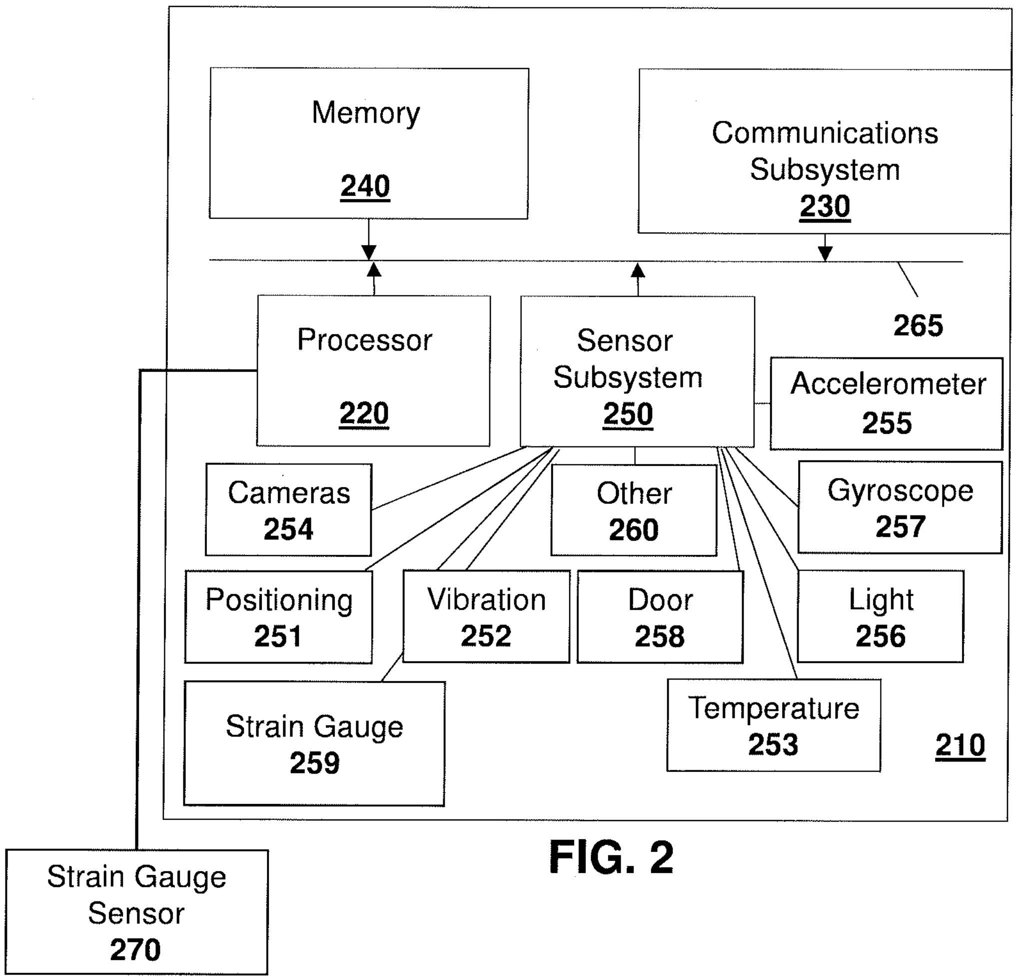

Memory
240
Communications Subsystem
230
265
Processor
220
Sensor Subsystem
250
Accelerometer
255
Cameras
254
Other
260
Gyroscope
257
Positioning
251
Vibration
252
Door
258
Light
256
Strain Gauge
259
Temperature
253
210
Strain Gauge Sensor
270

FIG. 2

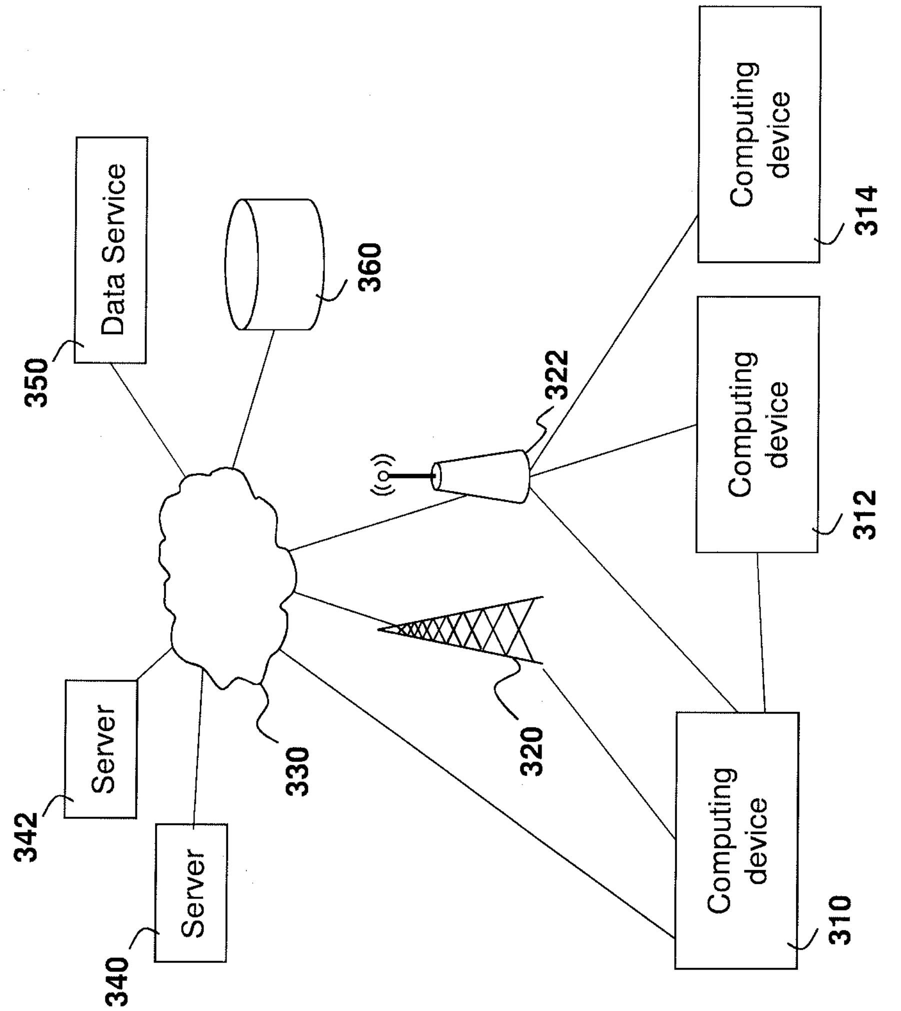

Data Service
350
360
Computing device
314
Computing device
312
322
330
320
Server
342
Server
340
Computing device
310

FIG. 3

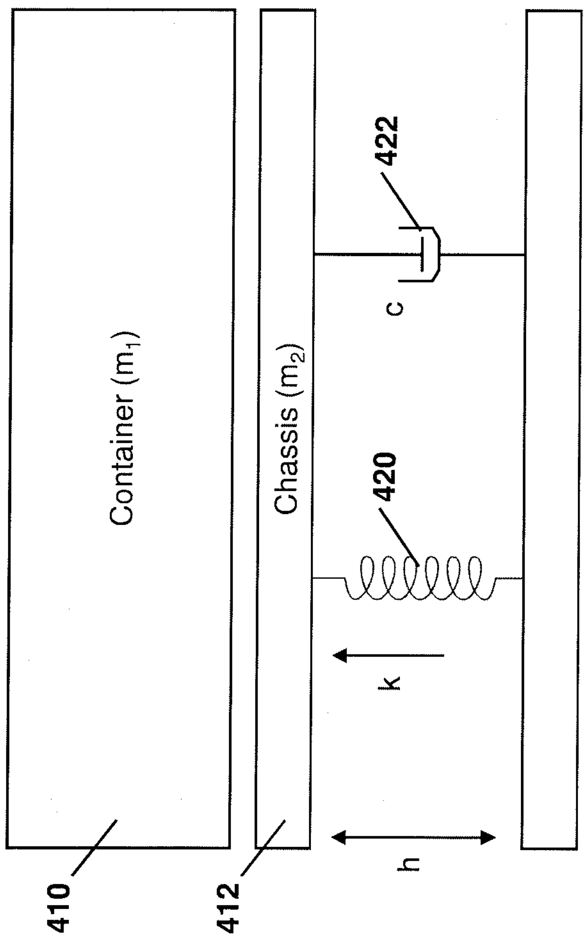


FIG. 4

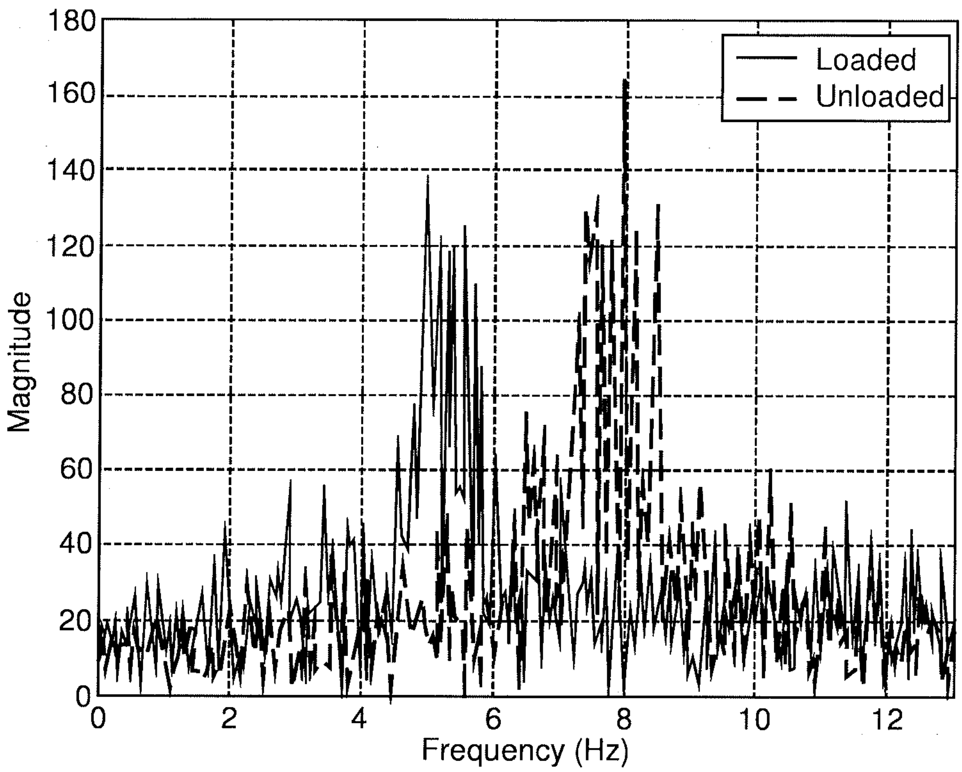

180
160
140
120
100
80
60
40
20
0
Magnitude
0
2
4
6
8
10
12
Frequency (Hz)
Loaded
Unloaded

FIG. 5

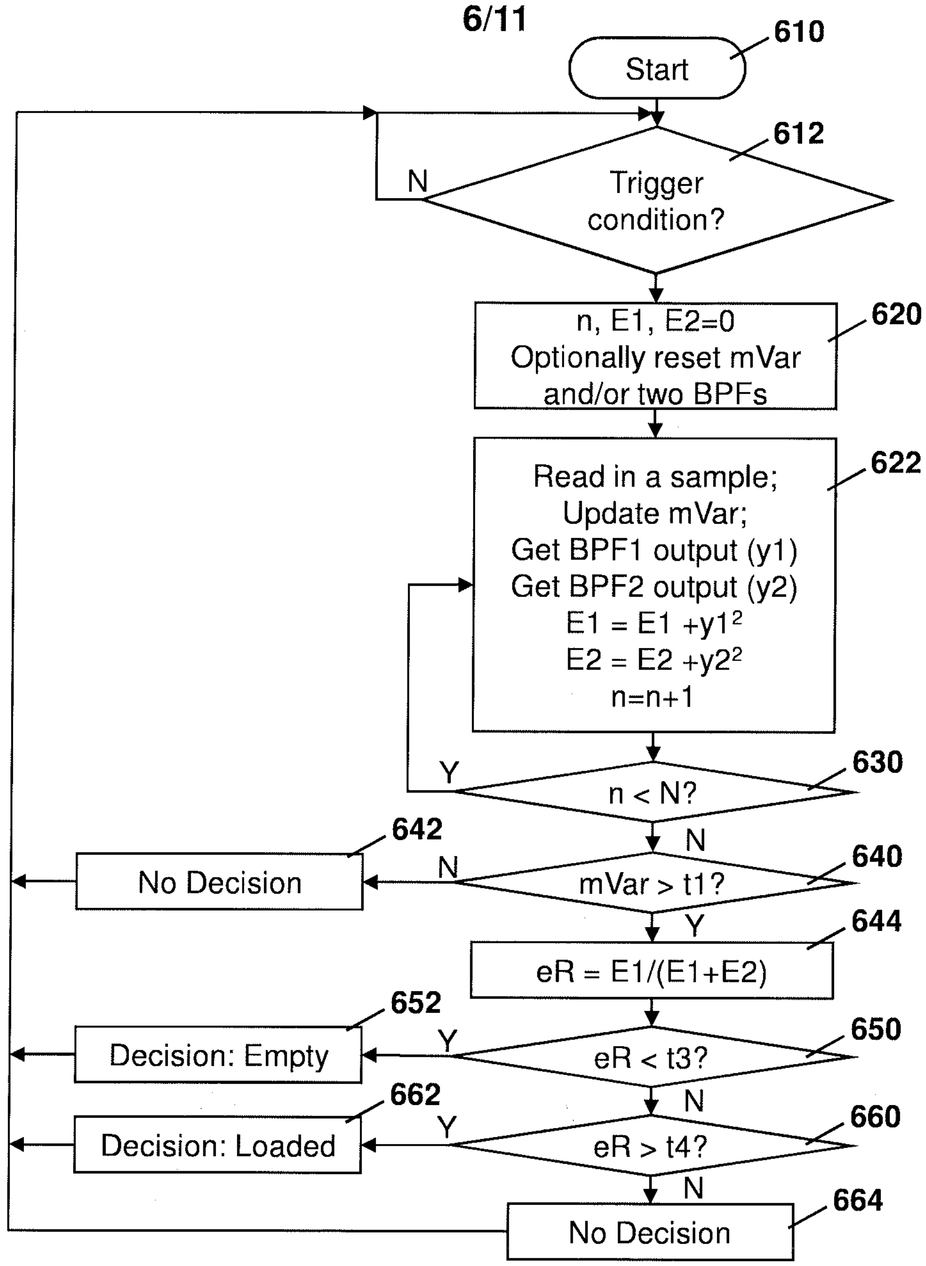

Start
610
Trigger condition?
612
N
n, E1, E2=0
Optionally reset mVar
and/or two BPFs
620
Read in a sample;
Update mVar;
Get BPF1 output (y1)
Get BPF2 output (y2)
E1 = E1 +y1²
E2 = E2 +y2²
n=n+1
622
n < N?
630
Y
N
mVar > t1?
640
No Decision
642
N
Y
eR = E1/(E1+E2)
644
eR < t3?
650
Decision: Empty
652
Y
N
eR > t4?
660
Decision: Loaded
662
Y
N
No Decision
664

FIG. 6

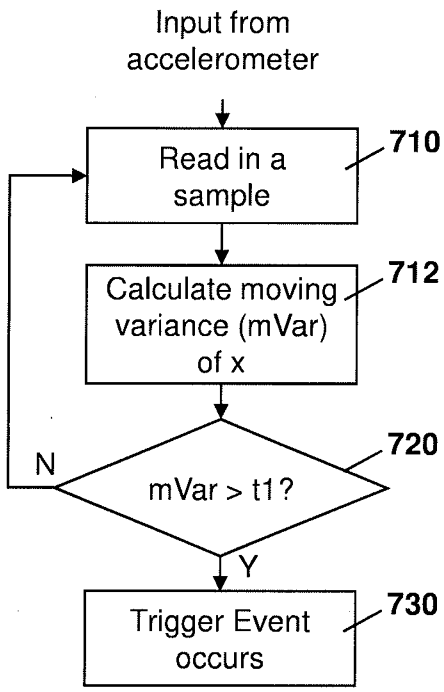

Input from accelerometer
Read in a sample
710
Calculate moving variance (mVar) of x
712
mVar > t1?
720
N
Y
Trigger Event occurs
730

FIG. 7

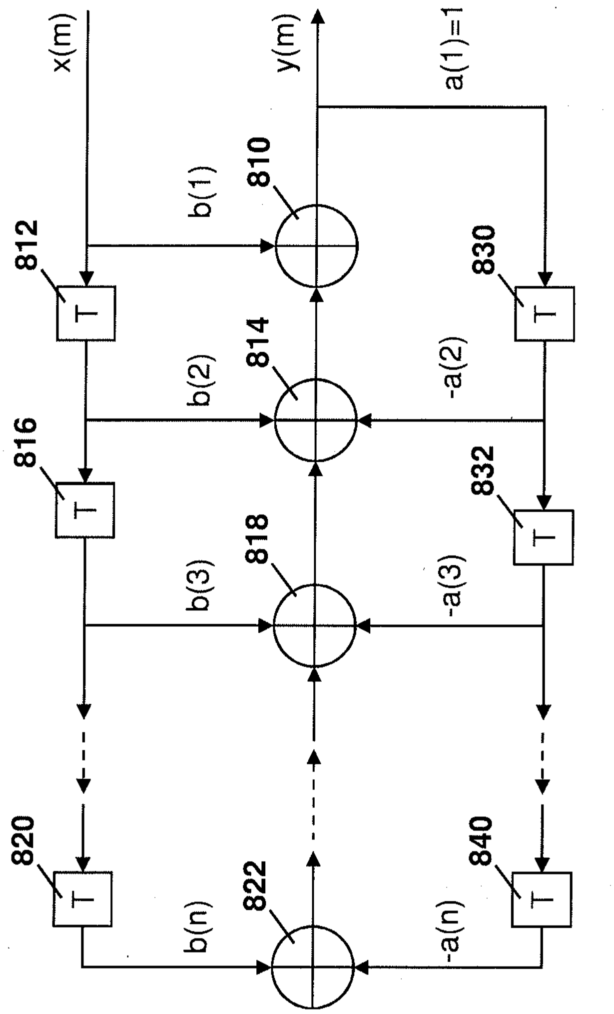

x(m)
y(m)
a(1)=1
b(1)
810
812
830
T
b(2)
814
-a(2)
816
832
b(3)
818
-a(3)
820
840
b(n)
822
-a(n)

FIG. 8

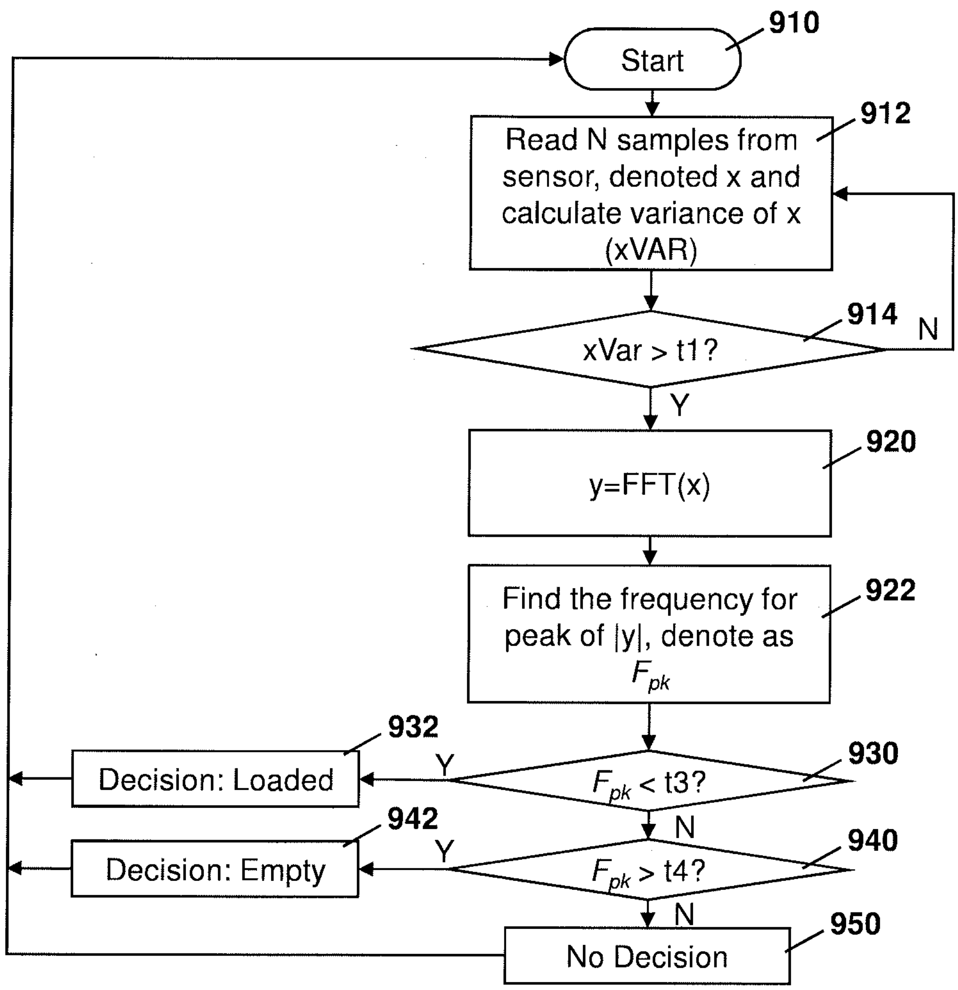
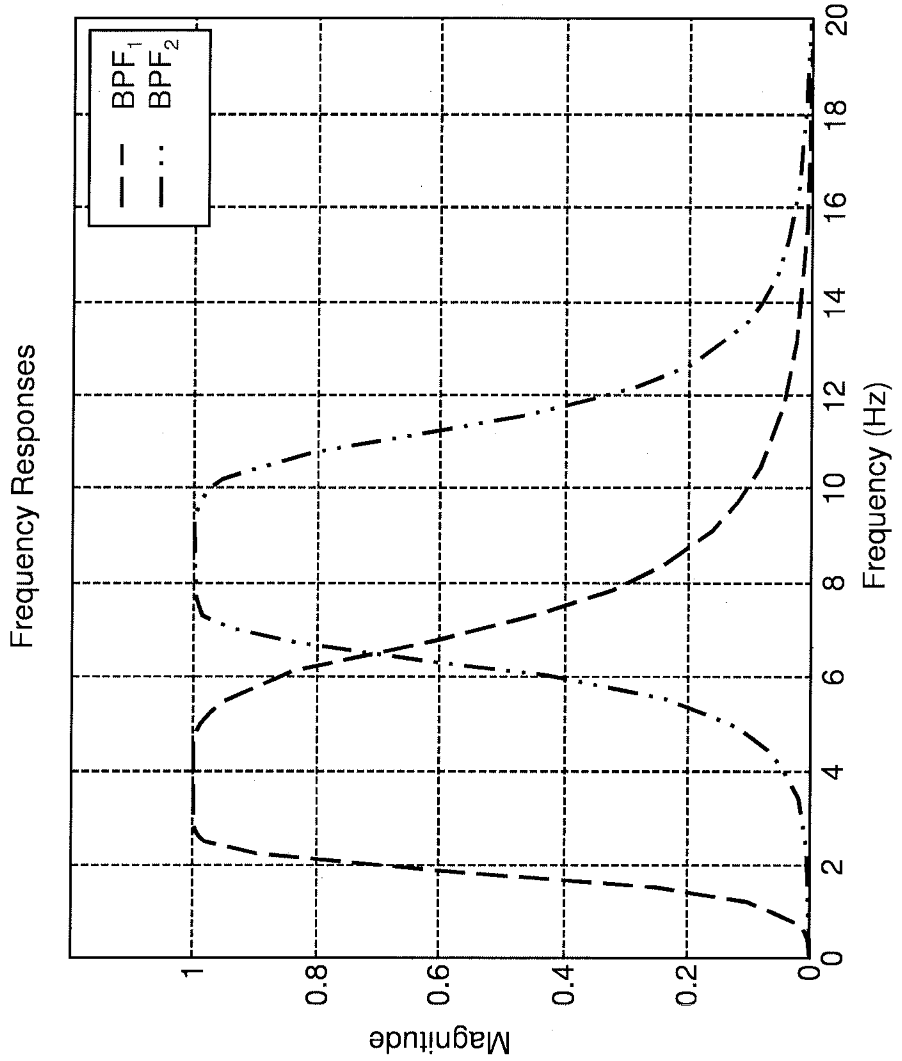

910
Start
912
Read N samples from sensor, denoted x and calculate variance of x (xVAR)
914
xVar > t1?
N
Y
920
y=FFT(x)
922
Find the frequency for peak of |y|, denote as F_{pk}
932
Decision: Loaded
Y
930
F_{pk} < t3?
N
942
Decision: Empty
Y
940
F_{pk} > t4?
N
950
No Decision

FIG. 9



Frequency Responses
Magnitude
Frequency (Hz)
BPF1
BPF2
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
12
14
16
18
20

FIG. 10

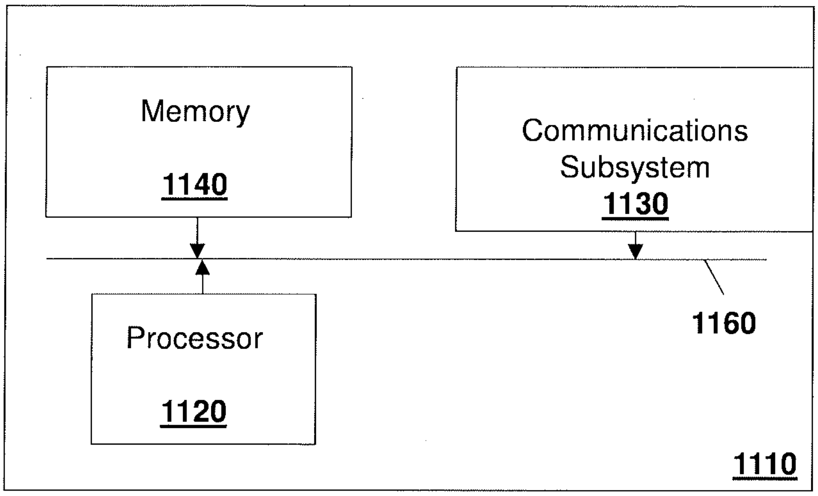

Memory
1140
Communications
Subsystem
1130
Processor
1120
1160
1110

FIG. 11

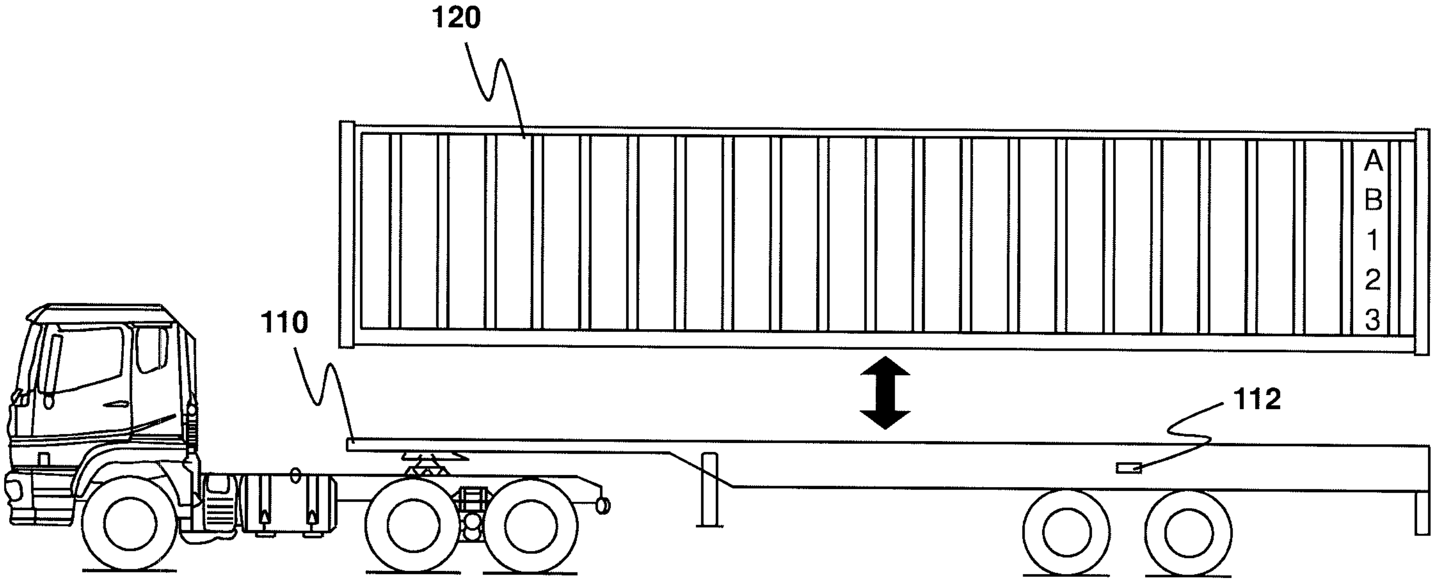


FIG. 1