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(54) **Title:** SYSTEM FOR MANAGING INTERCONNECTED OBJECTS

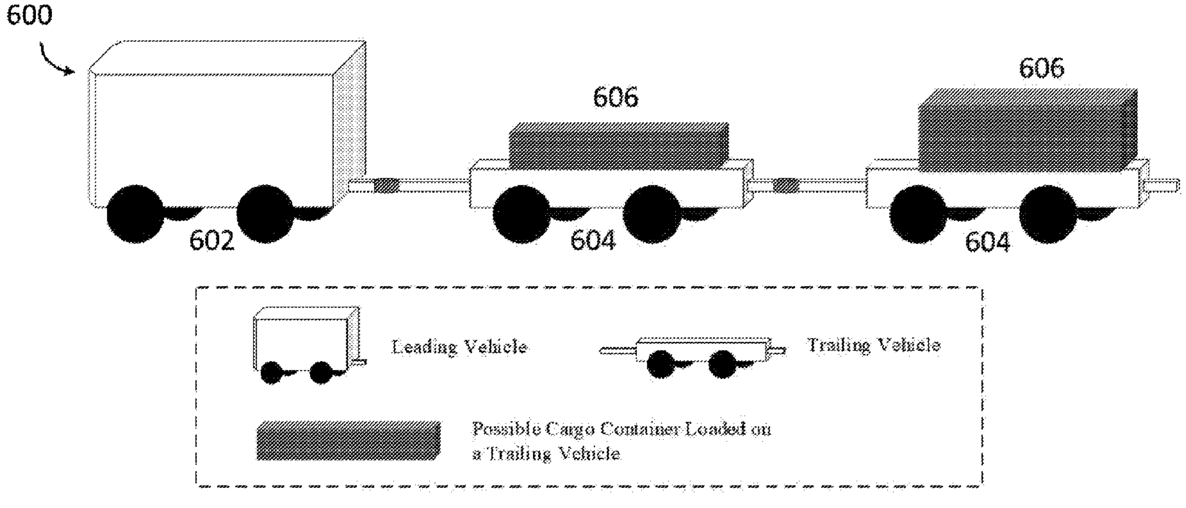

Figure 6

(57) **Abstract:** Disclosed herein is a system for managing one or more objects of a plurality of interconnected objects, the objects including at least one first object and at least one second object, the system comprising: an active module attachable to each first object and adapted to communicate with an external positioning network to detect real time geolocation of the respective first object; a processor for receiving a signal from the active module comprising the real time geolocation and determining a real-time heading and velocity of each first object; and a collision detection mechanism to prevent at least one said interconnected object from colliding with a further object.

[Continued on next page]

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System for Managing Interconnected Objects

Field of Invention

The present invention relates to a system for managing interconnected objects. In particular, the present invention relates to a system for managing a train of vehicles, and such a train of vehicles comprising the system.

Background

Tracking ground support equipment (GSE) in a high accuracy manner is crucial for both airport safety and optimal management of airport assets but the related researches and products are scarce. Tracking a multi-carriage logistics train is obviously most challenging compared with other single-carriage GSEs. The persistent increase in annual air traffic raises the importance of such optimal management of GSE to minimize the overheads and maximize the airport operational efficiency.

Current approaches use visual scans of crews to guarantee a safe distance between aircraft and GSE. Visual inspection is unreliable for collision detection and identifying shocks imposed on aircraft, especially those caused by moving GSEs such as tank trucks, shuttles and cargo-transit trains. This is due to the inability for visual inspections to be constant over the full ground area through which GSEs can travel, and due to the small lead time for identifying potential collisions before moving GSEs impact aircraft and other objects. These latent collisions result in potential aviation risks and increased overheads. A natural solution is to employ high accuracy tracking technologies to automatically detect collisions. However, this requires centimetre-level positioning accuracy of GSEs. Existing technologies – e.g. Global Positioning Systems (GPSs) and Radio-frequency identification (RFID) – cannot achieve such levels of accuracy. GPS and other sensors cannot be placed over some trailing vehicles (e.g., dollies) since cargo containers and luggage are loaded onto the surfaces where GPS units and sensors would need to be placed to facilitate detection.

The GSE tracking problem has the following challenges. Firstly, as mentioned above traditional GPS and RFID technologies only offer positioning accuracy in meter level. This cannot support reliable collision detection, particularly for vehicles that normally move near each other. Secondly, if the leading vehicle and trailing vehicles are localized by GPS (or RFID) individually, there is no integrated information provided for a train of vehicles – i.e. each vehicle is treated individually. The structure of the train, such as the number and linking sequence of trailing vehicles, is unknown. However, such information is necessary for dynamic and reliable GSE collision detection.

In addition, existing methods fail to account for changes in the number and linking sequence of trailing vehicles during a single trip of a train. Such changes are common in airport operations. Existing tracking technologies are not able to automatically monitor and update the changes of connected trailing vehicles. In addition, in failing to understand the sequence of trailing vehicles and/or their position relative to other vehicles, existing methods cannot solve the heading problem effectively, insofar as it relates to the headings of trailing vehicles.

Some geomagnetic field based methods have been proposed. However, these methods suffer from inaccuracies and data corruption in electromagnetically noisy environments. Inertial unit based methods have also been proposed. However, these methods fail to provide reliable data due to integrator unit introducing an accumulated error – i.e. the longer the time that the train runs, the greater the error. This means extra auxiliary correction mechanisms are needed to periodically calibrate and correct for the accumulated error.

Airport GSE tracking problems do not apply similarly to tracking problems experienced in other industries such as robotic, autonomous navigation and driving, automated agriculture industries and so forth.

The methods and systems described herein have been developed in light of the abovementioned difficulties and may solve, or reduce, one or more of those difficulties.

Summary

Disclosed herein is a system for managing one or more objects of a plurality of interconnected objects, the objects including at least one first object and at least one second object, the system comprising:

an active module (AM) attachable to each first object and adapted to communicate with an external positioning network to detect real time geolocation of the respective first object;

a processor for receiving a signal from the AM comprising the real time geolocation and determining a real-time heading and velocity of each first object; and

a collision detection mechanism to prevent at least one said interconnected object from colliding with a further object.

The system may further comprise at least one passive information module (PIM) attachable to each second object, for detecting motion of the respective second object, the processor being further configured to receive a detected motion from each PIM, and determine a real-time heading for each second object. The first object and second objects may be arranged in a train, the system further comprising a tag accessory board (TAB) and base accessory board (BAB) for each second object, wherein:

for each second object, the PIM determines and transmits a signal comprising a heading of the respective second object, via the TAB of the respective second object, to a BAB of another object in the train;

each second object that receives a signal via its respective BAB appends to the signal, via the respective PIM, its heading and transmits via its TAB the signal comprising the appended heading to a BAB of another object in the train; and

when the first object receives a signal via its BAB, it sends to a remote server a signal comprising the heading of each object in the train.

The processor may be configured to determine a real-time position of each PIM relative to the AM.

The system may further comprise a remote server configured to receive the signal transmitted from AM and a signal transmitted from each PIM.

The processor may further comprise a moving-object tracking algorithm for determining the real time velocity of multiple points on each object.

The system may further comprise a data fusion mechanism comprising at least one of a gyroscope, magnetometer and accelerometer, the processor determining the real-time heading and velocity of the first object based on measurements from the data fusion mechanism.

At least one first object may be a leading vehicle, and each said second object may then be a trailing vehicle in a train of interconnected vehicles. In some other embodiments, the first object may be a trailing vehicle – for example, where the first object shunts the second objects.

The processor may either be:

located, in use, on the plurality of interconnected objects; or

located remotely, the AM being configured to communicate wirelessly with the processor.

Also disclosed herein is a train comprising:

a system according to any one of claims 1 to 10; and

each first object is a first vehicle and each second object is a second vehicle, wherein the system is attached to said vehicles.

The AM may be attached on a top surface of the first vehicle, and each PIM is attached below a top surface of the respective second vehicle to avoid contact with cargo on the top surface. Each PIM may be attached to an underside of the respective second vehicle.

The processor may be configured to determine a real time position of one or more points of the vehicles in the train, by the equation:

$$\begin{cases} \boldsymbol{X}_{\mathcal{M}}^{t+1} = \boldsymbol{\Phi}_{\mathcal{M}}\boldsymbol{X}_{\mathcal{M}}^{t} + \boldsymbol{G}_{\mathcal{M}}\boldsymbol{W}^{t} \\ \boldsymbol{Y}^{t} = \boldsymbol{H}_{\mathcal{M}}\boldsymbol{X}_{\mathcal{M}}^{t} + \boldsymbol{V}^{t} \end{cases}$$

the terms of which are described herein.

The processor may be configured to apply a moving-object tracking algorithm implementing Kalman filtering, to determine a real-time velocity of a point of interest on the train.

The least each second vehicle may comprise an identifier, each PIM communicating the respective identifier, with the detected motion of the respective second vehicle, to the processor. The processor may be configured to determine a linking-sequence of vehicles in the train from each identifier, whereby the linking-sequence and a number of vehicles define a structure of the train. Each second vehicle that comprises an identifier may further comprise a tag accessory board (TAB) and each vehicle comprises a base accessory board (BAB) the TAB of one vehicle transmitting the identifier for that vehicle to the BAB of a neighbouring one of said vehicles. TAB may be positioned at a leading end of the respective vehicle and the BAB is positioned at a trailing end of the respective vehicle. The TAB may further be configured to transmit the signal from the respective PIM to the BAB of the neighbouring one of said vehicles. The first vehicle may comprise an identifier, the AM being configured to transmit to a remote server a linking-sequence comprising the identifiers of the first vehicle and second vehicles in an order determined based on a signal received by the BAB of the first vehicle.

Each AM and PIM may comprise a data fusion mechanism comprising at least one of a gyroscope, magnetometer and accelerometer.

Also disclosed herein is a method of managing one or more vehicles of a plurality of interconnected vehicles, including:

at least one first vehicle with an active module (AM) attached thereto; and

at least one second vehicle, each said second vehicle comprising:

at least one passive information module (PIM);

a tag accessory board (TAB);

a base accessory board (BAB); and

a physical identifier,

the method comprising:

calculating, using the one or more PIMs of each second vehicle, a real-time heading of the respective second vehicle;

accumulating the real-time heading and identifier of each second vehicle in the train:

by producing a signal at an initial said second vehicle, the signal comprising the real time heading and physical identifier of the initial second vehicle; and

relaying the signal to each other said second vehicle in series, each other second vehicle adding to the signal the real-time heading and physical identifier of the respective second vehicle;

relaying the signal the first vehicle, once all second vehicles have added the respective real-time heading and physical identifier to the signal; and obtaining, via the AM, a real time geolocation and real-time heading of the first vehicle, and a vehicle identifier for each vehicle in the plurality of interconnected vehicles;

calculating, from the signal, the geolocation and real-time heading of the first vehicle and the identifier for each vehicle, a real-time position and velocity of each vehicle in the plurality of interconnected vehicles, and a structure of the plurality of interconnected vehicles;

consolidating the real time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles in a database,

adjusting the real time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles to prevent at least one vehicle from colliding with a further object.

Calculating the real time position and velocity of each vehicle in the plurality of interconnected vehicles may comprise calculating, at the first vehicle, the real time position and velocity of each vehicle in the train from the signal, the real time geolocation and real-time heading of the first vehicle.

The real time position and velocity of each vehicle in the plurality of interconnected vehicles may be transmitted to a remote server.

Brief description of Figures

Embodiments of the invention will be described, by way of non-limiting example only, with reference to the accompanying drawings in which:

Figure 1 illustrates a system for managing one or more objects of a plurality of interconnected objects;
Figure 2 illustrates the schematic of an active positioning module;
Figure 3 illustrates the schematic of a passive information module;

Figure 4 illustrates the schematic of an accessory board;

Figure 5 illustrates prototypes of the system for managing one or more objects of a plurality of interconnected objects;

Figure 6 illustrates an example multi-carriage train;

Figure 7 illustrates placements of component of the system for managing one or more objects of a plurality of interconnected objects;

Figure 8 illustrates overall placement scheme of the system for managing one or more objects of a plurality of interconnected objects;

Figure 9 illustrates an example geodetic coordination system and key physical sizes of an example multi-carriage train;

Figure 10 illustrates labels for communication channel and logic presentation;

Figure 11 illustrates an example communication logic of the system for managing one or more objects of a plurality of interconnected objects;

Figure 12 illustrates an irregular pentagon defines by the structure of a train; and

Figure 13 illustrates an example BAB and TAB determining linking sequence.

Detailed Description

The present disclosure relates object – e.g. vehicle – management in a multi-object system. The present methods can be used for implementing a Real-time On-board Positioning and Heading System (ROPHS) for obtaining real-time, high accuracy status of all types of GSE, especially multi-carriage logistics trains. The system can use this information to efficiently detect collisions and optimise asset utilisation, particularly in the aviation industry.

In present teachings relate more relevantly to multi-carriage systems, as distinct from single-carriage GSEs though they may be applied in a single-carriage GSE context. The single-carriage GSE in the present disclosure is treated as a special multi-carriage train which only has one leading vehicle and no trailing vehicles.

In the present disclosure, the term "vehicle" will be used. However, the same teachings can be applied to "objects" more generally, including carriages of a multi-carriage train, interconnected sleds and the like. The terms “Head”, "Lead" and similar denote the head or leading vehicle in a train, and the terms “Slave”, “Trailing” and similar refer to vehicles trailing behind the head vehicle.

Described below are the system structure, information streaming logic and tracking algorithms of ROPHS in accordance with present teachings. It will be understood by the skilled person that the various circuit components identified herein may form a single unit on each object, may be separated into separate circuits and so forth, without detracting from the applicability of the present methods and all such variations are intended to fall within the scope of the present disclosure.

Embodiments of the present system provide an integrated and comprehensive solution for airport or other GSE tracking and collision detection that handle the challenges listed in the background part of the present disclosure. Such embodiments may employ a Global navigation satellite systems (GNSS) since such systems: 1) do not require the setting of landmarks; 2) are mature technologies; 3) are commercially mature; 4) and include real-time kinematic systems (RTK systems – one kind of advanced GNSS solution) with centimetre-level accuracy and precision.

The illustrative embodiments generally focus on multi-carriage logistics trains having a powered leading vehicle and one or several non-powered trailing vehicles. The present teachings may, however, be extended to systems with multiple powered vehicles – i.e. "first vehicles" – that may be positioned together at the head of a train, or over the length of the train. Similarly, the present teachings may extend to trains in which the trailing vehicle, or other non-head vehicle, is the powered vehicle – i.e. the lead vehicle is non-powered.

Systems disclosed herein can be used to determine status of vehicles and trains, including: (a) the accurate position and velocity of any point on a train, and (b) the alterable number and linking sequence of trailing vehicles at any time in a trip. Embodiments usually use real-time kinematics (RTK) to obtain geolocation of the leading vehicle, gyroscopes, magnetometers and accelerometers to obtain headings of all vehicles. A geometry-based recurrence algorithm is presented for calculating the positions of any trailing vehicles. A moving-object tracking algorithm can also be used to compute the precision-improved locations and real-time velocities of the whole train.

In an embodiment, the present disclosure relates to a system for managing one or more objects of a plurality of interconnected objects, the objects including at least one first object and at least one second object. As used herein, the terms “object” and similar will generally refer to a “vehicle”, such as a trolley, engine, vessel and others. The objects may operate in a pre-defined area, for example a tarmac area in an airport-or may operate in an open area. It will be appreciated that in some examples at least one of the second objects is also a first object. That is, the interconnected objects may all be first objects.

Such a system 100 is shown in Figure 1. Broadly, the system 100 comprises:

an active positioning module (APM) 102 attachable to each first object and adapted to communicate with an external positioning network to detect real time geolocation of the respective first object;

a processor 104 for receiving a signal from the APM comprising the real time geolocation and determining a real-time heading and velocity of each first object; and

a collision detection mechanism 106 to prevent at least one said interconnected object from colliding with a further object.

In some embodiments, the processor 104 can be integrated into the APM module.
As mentioned above, while the disclosure relates to "objects" more generally, embodiments are given with respect to "vehicles" for the purpose of illustration only. The APM is a physical part of system 100 for the leading vehicle (i.e., the first object). The APM is designed to obtain the real-time position and the heading of the first vehicle or

leading vehicle. In the present disclosure, at least one said first object is a leading vehicle, and each second vehicle is a trailing vehicle in a train of interconnected vehicles.

The APM is shown schematically in Figure 2. There may be a plurality of first objects as mentioned above, with an APM on each. Each APM may include a RTK, and APM 102 can directly obtain the precise position via a positioning system – e.g. RTK. To facilitate transmission and/or reception of signals to/from a remote server, the APM 102 is placed overhead on the leading vehicle. The APM contains an embedded micro-processor 201 and peripheral modules includes memory 202, a RTK module 204, a GNSS antenna 206, an internet port 208 (e.g. Wi-Fi), a Bluetooth module 210, an inertial unit 212 (digital gyroscope), a magnetometer 214, an accelerometer 216, a RS232 interface 218, and a battery 220. The mentioned peripheral modules communicate with the micro-processor 201 via serial ports and/or general purpose input output (GPIO) (not shown).

In some embodiments, each first vehicle includes a tag accessory board (TAB) 108 and/or base accessory board (BAB) 110, and usually at least a BAB. The APM connects to the TAB and/or BAB via any appropriate communication protocol – e.g. hardwired connection for RS232. In another example, if wired RS232 is not applicable, wireless Bluetooth could be a substitute. As will be discussed in more detail, said TAB 108 and BAB 110 are designed to identify the real-time number and linking sequence of the trailing vehicles (i.e. the second objects) of a train.

The APM 102 relies on RTK to determine the accurate position of the point on the leading vehicle where the APM 102 is placed. In order to obtain the heading of the leading vehicle and afterwards jointly determine the status of the whole train, information from a data fusion mechanism comprising one or more of a gyroscope, magnetometer and accelerometer (GMA) is integrated to obtain the robust heading of the leading vehicle (i.e., the first object). The inertial unit (digital gyroscope) determines the real-time heading of the train. This can be used to calculated all the headings of the leading vehicle and the trailing vehicle(s). In another example, if the environment is not significantly noisy – e.g. electromagnetically noisy – the magnetometer can directly provide the headings of the train. It will be appreciated that the present disclosure uses the dimension data of a train, the heading(s) of each trailing vehicle(s) and the position of the leading vehicle to determine the positions of any point on the train.

As will be discussed further below, each trailing vehicle includes at least one passive information module (PIM). A PIM detects motion (e.g. heading) of the respective trailing vehicle. The processor or micro-processor 201 is configured to receive a detected motion from each PIM, and determine a real-time heading for each trailing vehicle. In general, the leading and trailing objects are arranged in a train structure. The PIM of each trailing vehicle determines and transmits a signal comprising a heading of the respective trailing vehicle, via the TAB of the respective trailing vehicle, to a BAB of another vehicle in the train. Each trailing vehicle that receives a signal via its respective BAB appends to the signal, via the respective PIM, its heading and transmits via its TAB the signal comprising the appended heading to a BAB of another vehicle in the train. When a leading vehicle receives a signal via its BAB, it sends to a remote server a signal comprising the heading of each object in the train. For example, the rearmost trailing vehicle (which does not receive a signal via its BAB) sends its heading and identifier to the vehicle that immediately precedes it in the train. That immediately preceding vehicle appends its identifier and heading to the signal and forwards it, via its TAB, to the BAB of the next preceding vehicle and so on until the signal reaches the leading vehicle. The leading vehicle determines the heading of all vehicles – e.g. from a known, relative coordinate system for each vehicle – and transmits the headings to a remote server for collision detection. The transmission to a remote server allows a single server to has visibility of all vehicles in a work area – e.g. airport tarmac – and ensure each vehicle avoids collision with all others. This removes the need for vehicles to have independent visibility of their surrounding area for collision avoidance, which can be difficult where there are obstructions to vision.

The processor 201 may determine the real-time heading and velocity of the first object based on measurements from the data fusion mechanism. APM 102 could alternatively return precise velocity and heading information for the leading vehicle, using data fusion and moving-object tracking algorithms, such as those implementing Kalman filtering discussed below. The APM 102 shares information of the whole train with a remote server via an Internet connection or other network connection. The remote server can thus be used as an integrated aviation asset management system – in embodiments, the server is one part of the processor 104.

The GNSS or other antenna/receiver of APM 102 receives the GNSS signals from satellites or other devices/sensors such as BEIDOU, GPS, GLONASS, GALILEO and others. The RTK correction signals received by APM 102 are transmitted from the reference RTK base station via Internet. The RTK module calculates the current accurate and precise position of APM 102 based on the GNSS signals and RTK correction signals. In one example, the RS232 interface is for wired communication with the corresponding TAB 108 and/or BAB 110. In other examples, a Bluetooth connection is employed.

In an embodiment, system 100 further comprises at least one of the abovementioned passive information modules (PIM) 112 attachable to each second, or trailing vehicle. The PIM detects motion of the respective second vehicle. The processor 104 is further configured to receive a detected motion from each PIM, and determine a real-time heading for each second vehicle. It will be appreciated that in some scenarios it is the remote server of processor 104 that receives the signal transmitted from APM and from each PIM. PIM 112 is a physical part of the system for the trailing vehicle(s). APM and PIMs communicate with each other to share the information for further data fusion. In some embodiments, the APM is designed to obtain both the real-time position and heading of the leading vehicle, whereas each PIM is able to obtain the real-time heading of the respective trailing vehicle only. As will be discussed in detail, it is processor 104 that determines the real-time position of each PIM relative to the APM. It achieves this function using a geometry-based positioning algorithm 114 and moving-object tracking algorithm 116 with information from both APM 102 and PIM 112.

Figure 3 shows a schematic of a PIM 112. As with all schematics set out herein, modules are shown separately for illustration purposes only. Modules may be combined or separated in any manner, while achieving the desired functionality, and fall within the scope of the present disclosure.

The PIM contains an embedded micro-processor 301 and peripheral modules including memory 302, an inertial unit 304 (digital gyroscope), a magnetometer 306, an accelerometer 308, a Bluetooth 310, a RS232 interface 312, and a battery 314. The mentioned peripheral modules communicate with the microprocessor via serial ports, GPIO or other connection. The GMA is for heading. In the embodiments shown, each trailing vehicle has a TAB and BAB. Each PIM connects, via RS232 or other protocol, to the two accessory boards (i.e., TAB 108 and BAB 110). In particular, the PIM is connected wiredly to the corresponding TAB 108 and BAB 110.

In general, APM 102, which can directly obtain the precise position via RTK, is placed overhead on the leading vehicle. PIM 112, through the information from which the positions of trailing vehicles can be estimated , is deployed under surface below each trailing vehicle. This avoids placing the GNSS or other antenna overhead on special vehicles such as dollies, where damage may occur due to loading and unloading of the vehicle. The APM and PIM(s) jointly build the proposed system 100 capable of determining the real-time headings, positions and velocities of the whole train. In one example, system 100 includes exactly one APM and at least one PIM.

The on-board positioning and heading system communicates with the remote server (deployed in remote control centre) via internet. The APM on the leading vehicle shares relevant information with the PIM(s) on the trailing vehicle(s) via proper data link. The possible data link could be wireless Bluetooth, wireless ultra-wideband (UWB) electromagnetic channels and/or a wired Data Bus such as USART (universal synchronous and asynchronous receiver-transmitter, as RS232, RS485), Universal Serial Bus (USB), IIC (I2C, inter-integrated circuit) and others.

There is no RTK in PIM 112. This is mainly due to RTK, and GNSS antennae more generally, being expensive when compared with GMA – integrating a RTK module into every PIM will incur unnecessary cost. Moreover, the top surface of a dolly car and some other types of trailing vehicle are not appropriate for installation of GNSS antennae. Therefore, the locations of any trailing vehicles are determined using geometry based positioning algorithms 114 and moving-object tracking algorithms 116 that require information from both APM and PIM(s). For example, processor 104 or its associated memory comprises the moving-object tracking algorithm for determining the real-time velocity of multiple points on each object. In fact, by determining the velocity of only the extremities of corners/edges of a vehicle – i.e. the extremities of each vehicle, the define a conceptual bounding box for the vehicle as a whole – there may be no need to determine the velocity or other property of any other point especially, particularly for objects having fixed shape.

As mentioned above, in some embodiments both APM 102 and PIM 112 connect to accessory boards (ABs), via RS232. An illustrative schematic of an accessory board is given in Figure 4. Said accessory board consists of an embedded micro-processor 401 and modules including a UWB module 402, a battery 404, a RS232 interface 406 and a Bluetooth 408. Electromagnetic signals from the UWB are used to determine, and update, the number and linking sequence of the trailing vehicles. The mentioned modules communicate with the processor 401 via serial ports and/or GPIO. The AB shown in Figure 4 can operate either in TAB (e.g. transmitter) mode (108) or BAB (e.g. receiver) mode (110). TAB 108 and BAB 110 are accessories of the APM 102 and PIM(s) 112. Prototypes of system 100 are given in Figure 5. In an embodiment, TAB 108 and BAB 110 are physically identical, and they have different embedded code (i.e., different working mode).

The connection between the BAB and a TAB is mainly used for ranging and determining the changeable number and link sequence of trailing vehicles. The ranging mechanism works under symmetric-double-sided two-way time-of-arrival (SDS-TW-TOA) protocol based on IEEE Standard 802.15.4a, and RS232 or other communication protocol is used to communicate with corresponding APM or PIM. Thus, one BAB and one TAB are required for pairing. The UWB module in BAB acts as base (also known as anchor) node while the UWB module in TAB acts as tag node. Thus the UWB module in BAB acts as BASE (also known as ANCHOR) node while the UWB module in TAB acts as TAG node. The ranging devices could also be Bluetooth and so on, if UWB devices are not applicable.

As hinted at above, processor 104 can be distributed across APM 102 and PIMs 112. The processor may be centralised on the train, or may be located remotely to receive signals from the train and calculate, for example, heading, position and velocity. The processor 104 may instead be partly located on the train and partly locate remotely. In some examples, processor 104 is located, in use, on the plurality of interconnected objects. In some other embodiments, the processor is located remotely, and in such cases the APM is configured to communicated with the processor wirelessly. The processor computes the real-time status of the leading vehicle as well as that of the whole train based on: (a) all information collected by sensors, (b) the geometry based positioning algorithm, and (c) the moving-object tracking algorithm. For example, the processor 104 uses the moving-object tracking algorithm for determining the real time velocity of multiple points on each object. In another example, each APM and PIM comprises a data fusion mechanism comprising at least one of a gyroscope, magnetometer and accelerometer, the processor determining the real-time heading and velocity of the first object based on measurements from the data fusion mechanism.

Collision detection mechanism 106 refers to a device or system that determines, from the real-time heading, velocity and geolocation of an object or plurality of interconnected objects, whether the object or plurality of interconnected objects is in danger of colliding with a further object. That "further object" may be anything collision with which is desirable to avoid, such as another plurality of interconnected vehicles or objects, stationary vehicles or objects, fixed plant, machinery, buildings and the like. The "further object" term may also refer to an area it is desirable to avoid, such a grassy or muddy areas for vehicles that do not have good traction control.

Disclosed herein is also a train 600 comprising multiple interconnected objects as shown in Figure 6, and the system 100 as discussed above attached to those objects, where each object is a respective vehicle. Figure 6 is the 3D illustration of an example multi-carriage cargo-transit train. Said train is mathematically formulated as $H - S_{i_{[1]}} - \cdots - S_{i_{[k]}} - \cdots - S_{i_{[n]}}$ with five requirements:

(a) there is one and only one leading powered vehicle denoted as H – as discussed above, some embodiments may employ first, or powered, vehicles, but only one vehicle is in the "lead" ;

(b) this train includes $n \in \mathbb{N}$ non-powered trailing vehicles and $n \geq 1$;

(c) for trailing vehicle $k (1 \leq k \leq n)$, $i_{[k]}$ is the permanent physical identifier (PID), for any $1 \leq k < j \leq n$, $i_{[k]} \neq i_{[j]}$, and $i_{[k]} \in \{1, \ldots, N\}$ $(n \leq N)$, where N denotes the total number of trailing vehicles at an airport;

(d) for trailing vehicle $k (1 \leq k \leq n)$, k is the logic identifier (LID) and $k \in \{1,2, \ldots, n\}$;

(e) the LID of the leading vehicle is 0.

H is for the first object (i.e., 602) (leading vehicle) and S is for the second object (i.e., 604) (trailing vehicle). The trailing vehicles are assumed to be dollies. Sensors cannot be deployed on the top surfaces of dollies because loaded containers 606 are likely to cover the sensors, preventing them from reliable or normal operation, or potentially damaging them. In some scenarios, dollies similarly cannot accept the installation of a GNSS antenna over the top surface, this being one reason why there is no RTK in the PIM to obtain the geolocation of the trailing vehicles.

Given a train $H - S_{i_{[1]}} - \cdots - S_{i_{[k]}} - \cdots - S_{i_{[n]}}$, time points $\{1, \ldots, t, \ldots, T\}$, the status of the train at time t is defined as $\{(x_j^t, y_j^t, z_j^t, v_j^t, \theta_j^t) \mid j = 0,1, \ldots, n\}$ where: (a) (x_j^t, y_j^t, z_j^t) is the position (in a global geodetic coordinate system), v_j^t is the instantaneous velocity and θ_j^t is the heading of the vehicle j at time point t, respectively; (b) $j (0 \leq j \leq n)$ is the vehicle LID; (c) $j \in \{1, \ldots, n\}$ and $t \in \{1, \ldots, t, \ldots, T\}$, z_j^t is assumed to be a fixed constant height h_j and the ROPHS thus only needs to compute (x_j^t, y_j^t). Intuitively, the status of a train contains the position, heading, and velocity of each vehicle.

Figure 7A and 7B suggest a possible placement of APM 102 and PIM 112, respectively. The APM 102 is attached on a top surface of the first vehicle 602, and each PIM 112 is attached below a top surface of the respective second vehicle 604 to avoid contact with cargo on the top surface. For example in Figure 7B, each PIM is attached to an underside of the respective second vehicle. The APM requires open enough area to receive sufficient satellites signals. The PIM should be placed under surface below the trailing vehicles. As mentioned above, some trailing vehicles like dollies in an airport cannot accept an overhead deployment. Containers are loaded onto the top surface of a dolly as shown in Figure 6. For similar reasons, sensors cannot be deployed on the top surface of dollies because loaded containers are likely to cover the sensors and prevent normal operation of the sensors. The suggested TAB and BAB placement scheme is illustrated in Figure 7C. BAB 110 is placed in the rear of vehicles, including both leading and trailing vehicles. TAB 108 is deployed in the front of trailing vehicle(s).

The placement scheme and communication channels of the ROPHS system are shown in Figure 8, particularly the placement scheme for the APM, PIM(s), BAB(s), and TAB(s) on a train. The leading vehicle 602 shown contains exactly one APM and one BAB. Each trailing vehicle 604 includes exactly one PIM, one TAB and one BAB. The TAB on the proceeding vehicle and the BAB on the preceding vehicle build a pair as indicated by electromagnetic connections. In some embodiments, some or all of the information transmitting channels between APM 102 and BAB 110, PIM 112 and TAB 108, and PIM 112 and BAB 110 are wired (in order to guarantee the communication reliability), while the connection between BAB and TAB is wireless. In still further embodiments, the connection between BAB and TAB may be hardwired across carriage linkages, though this can be impractical for rapid connection and disconnection of some objects.

The software design of the ROPHS includes a geometry based positioning algorithm 114, moving-object tracking algorithm 116, and communication logic 120 (see Figure 1). Some or all of these functions may also be implemented in hardware and/or firmware. The main task of the software is to produce real-time status of train 600 based on raw information generated by hardware. The present disclosure uses the train $H - S_1 - S_2$ as a running example.

The geodetic coordinate systems (GCS) and parameters describing the physical size of train 600 are illustrated in Figure 9A and Figure 9B, respectively. Figures 9A and 9B show the coordinate systems in the context of an airport. Note that Figures 9A and 9B are just illustrative, and include only two trailing vehicles. In reality, if needed and applicable, the train could include three or more trailing vehicles. The logical ID of the leading vehicle of a train is assigned to be “0”, while the logical IDs of the trailing vehicles of a train are “1”, “2”, “3”, ... The physical ID is unique and permanent among for each vehicle in a logistics system. The logical ID is changeable, and depends on which train the vehicle links to and how many trailing vehicles the train has – i.e. the position of the respective vehicle in a linkage sequence.

In Figure 9A, a global geodetic coordinate system (GGEC) $x_e - O_e - y_e$ has the origin O_e chosen on the airport ground. Accordingly, when the present disclosure mentions the position of the leading vehicle, it infers point O_0 defined in the frame $x_e - O_e - y_e$ where APM 102 is placed. Similarly, when the position of a trailing vehicle is mentioned, where PIM 112 is placed, reference is made to points O_1 and O_2 and so on. Accordingly, the heading of the leading vehicle is the angle θ_0^t at time t, and the headings of the trailing vehicles are the angles θ_1^t and θ_2^t and so on. In general, in the present invention, the position of train 600 denotes all the relevant positions on the train, and the heading of a train means all the headings of both the leading and trailing vehicles. Typically, the points of interest on a train only contains the origins of all the relative coordinates, namely, the points where the APM(s) and the PIM(s) are placed.

In an embodiment, APM 102 and PIM(s) 112 are placed on vehicles along their axes of symmetry. At time t, for vehicle $j\ (j = 0,1,2)$, the present disclosure defines local geodetic coordinate system (LGCS) $x_j^t - O_j^t - y_j^t$ and $O_j^t = \left(x_j^t, y_j^t\right)'$is a two-dimensional column vector. Here, x_j^t and y_j^t are the coordinates in x_e and y_e axes respectively, and symbol $'$ is the transpose operator. Point O_j^t is the location of APM (j = 0) or PIM (j > 0) at time point t and the heading θ_i^t is defined as the angle between y_j^t axis of LGCS and $\boldsymbol{y}_e$ axis of GGEC. Note that the heights of GSE vehicles are considered constant. Thus, coordinate systems here only consist of two dimensions. In addition, several geometric parameters, e.g. l_j and g_j, are introduced to describe the physical size of the train 600 in Figure 9B. It is assumed that these parameters are constant and do not vary over time.

The positioning algorithm determines the real-time positions of the trailing vehicles. Considering $H - S_1 - S_2$ at time point t, the APM generates its longitude and latitude which can be transformed into the GGEC, i.e., $x_e - O_e - y_e$. Headings $\theta_j^t (j = 0,1,2)$ can be obtained from APM ($j = 0$) and PIM ($j > 0$). For trailing vehicle j, the position of its PIM O_j^t is computed by the following:

Given a train $H - S_1 - S_2 - \cdots - S_j$, time point $t \in \{1, \ldots, T\}$, two-dimensional column vector O_j^t , heading θ_j^t, geometry parameters l_j and g_j defined in Figure 9B, the following equation holds:

$$\begin{aligned} O_j^t &= O_{j-1}^t + Q'\left(\theta_{j-1}^t\right) \cdot \left[L_{j-1} + Q'\left(\Delta\theta_j^t\right) \cdot G_j\right] \\ &= O_0^t + \textstyle\sum_{k=0}^{j-1} \{Q'(\theta_k^t) \cdot [L_k + Q'(\Delta\theta_{k+1}^t) \cdot G_{k+1}]\} \end{aligned} \tag{1}$$

where:

$$\Delta\theta_j^t := \theta_j^t - \theta_{j-1}^t, L_j := (0, -l_j)', G_j := (0, -g_j)' \tag{2}$$

and

$$Q(\theta) := \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix}. \tag{3}$$

The processor 104 is also configured to apply a moving-object tracking algorithm implementing filtering – e.g. Kalman filtering – to determine a real-time velocity of a point of interest on the train. In particular, processor 104 is configured to determine a real-time position of one or more points of the vehicles in the train. In some examples there may be multiple points of interest. As mentioned above, for a fixed-shaped object, determining the velocity of one point is the same as determining the velocity of all points of a fixed-shape object.

The dynamics models that possibly match the running dynamics of the train are: (a) constant velocity (CV) model, (b) constant acceleration (CA) model, (c) Singer model, and (d) current statistics (CS) model. It will be appreciated that the CV and CS models are appropriate for slow moving patterns and straight-line trajectories while the CA and Singer models are suitable for relatively high manoeuvring and curved trajectories. Note that the running speed of GSE at an airport is limited (not greater than 25km/h), and similar limitations may be imposed in other working environments. Since the train at an airport usually runs in straight lines and only occasionally manoeuvres, the CV model and CS model should provide a generally good fit for the system dynamics.

For vehicle j ($j = 0,1,2$), the following illustrates how to track j and compute its velocity. Said moving-point tracking system is modelled by the Markov jump linear system as:

$$\begin{cases} \boldsymbol{X}_{\mathcal{M}}^{t+1} = \boldsymbol{\Phi}_{\mathcal{M}} \boldsymbol{X}_{\mathcal{M}}^{t} + \boldsymbol{G}_{\mathcal{M}} \boldsymbol{W}^{t} \\ \quad \boldsymbol{Y}^{t} = \boldsymbol{H}_{\mathcal{M}} \boldsymbol{X}_{\mathcal{M}}^{t} + \boldsymbol{V}^{t} \end{cases}, \tag{4}$$

where $\mathcal{M}$ is model label and $\mathcal{M} \in \{\text{CV}, \text{CA}, \text{Singer}\}$, t is discrete time point, $\boldsymbol{W}^t$ and $\boldsymbol{V}^t$ are process noise vector and measurement noise vector with proper dimensions, respectively, and $\boldsymbol{Y}^t$ denotes the measurement vector. If model $\mathcal{M}$ is CS, the equation becomes:

$$\begin{cases} \boldsymbol{X}_{\text{CS}}^{t+1} = \boldsymbol{\Phi}_{\text{CS}} \boldsymbol{X}_{\text{CS}}^{t} + (\boldsymbol{G}_{\text{CA}} - \boldsymbol{G}_{\text{CS}}) \overline{\boldsymbol{A}}^{t} + \boldsymbol{G}_{\text{CS}} \boldsymbol{W}^{t} \\ \quad \boldsymbol{Y}^{t} = \boldsymbol{H}_{\text{CS}} \boldsymbol{X}_{\text{CS}}^{t} + \boldsymbol{V}^{t} \end{cases}, \tag{5}$$

in which

$$\overline{\boldsymbol{A}}^{t+1} = e^{-\alpha\Delta t} \begin{bmatrix} \hat{a}_{jx}^{t} \\ \hat{a}_{jy}^{t} \end{bmatrix} + (1 - e^{-\alpha\Delta t}) \overline{\boldsymbol{A}}^{t}, \tag{6}$$

and the state vectors $\boldsymbol{X}_{\mathcal{M}}^{t}$, system matrices $\boldsymbol{\Phi}_{\mathcal{M}}$, noise driven matrices $\boldsymbol{G}_{\mathcal{M}}$ and measurement matrices $\boldsymbol{H}_{\mathcal{M}}$ are defined as:

$$\begin{aligned} \boldsymbol{X}_{\text{CV}}^{t} &= \left(x_j^t, v_{jx}^t, y_j^t, v_{jy}^t\right)' \\ \boldsymbol{X}_{\text{CA}}^{t} = \boldsymbol{X}_{\text{Singer}}^{t} = \boldsymbol{X}_{\text{CS}}^{t} &= \left(x_j^t, v_{jx}^t, a_{jx}^t, y_j^t, v_{jy}^t, a_{jy}^t\right)' \end{aligned} \tag{7}$$

$$\begin{aligned} \boldsymbol{\Phi}_{\text{CV}} &= \begin{bmatrix} \boldsymbol{I}_{2\times2} & \boldsymbol{0}_{2\times2} \\ \boldsymbol{0}_{2\times2} & \boldsymbol{I}_{2\times2} \end{bmatrix} \otimes \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \\ \boldsymbol{\Phi}_{\text{CA}} &= \begin{bmatrix} \boldsymbol{I}_{3\times3} & \boldsymbol{0}_{3\times3} \\ \boldsymbol{0}_{3\times3} & \boldsymbol{I}_{3\times3} \end{bmatrix} \otimes \begin{bmatrix} 1 & \Delta t & (\Delta t)^2/2 \\ 0 & 1 & \Delta t \\ 0 & 0 & 1 \end{bmatrix} \end{aligned} \tag{8}$$

$$\begin{aligned} \boldsymbol{\Phi}_{\text{Singer}} &= \boldsymbol{\Phi}_{\text{CS}} = \\ &\begin{bmatrix} \boldsymbol{I}_{3\times3} & \boldsymbol{0}_{3\times3} \\ \boldsymbol{0}_{3\times3} & \boldsymbol{I}_{3\times3} \end{bmatrix} \otimes \\ &\begin{bmatrix} 1 & \Delta t & (\alpha\Delta t - 1 + e^{-\alpha\Delta t})/\alpha^2 \\ 0 & 1 & (1 - e^{-\alpha\Delta t})/\alpha \\ 0 & 0 & e^{-\alpha\Delta t} \end{bmatrix} \end{aligned} \tag{9}$$

$$\boldsymbol{G}_{\mathrm{CV}} = \begin{bmatrix} \boldsymbol{I}_{2\times2} & \mathbf{0}_{2\times2} \\ \mathbf{0}_{2\times2} & \boldsymbol{I}_{2\times2} \end{bmatrix} \otimes \begin{bmatrix} (\Delta t)^2/2 \\ \Delta t \end{bmatrix}$$
$$\boldsymbol{G}_{\mathrm{CA}} = \begin{bmatrix} \boldsymbol{I}_{3\times3} & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times3} & \boldsymbol{I}_{3\times3} \end{bmatrix} \otimes \begin{bmatrix} (\Delta t)^2/2 \\ \Delta t \\ 1 \end{bmatrix} \tag{10}$$

$$\boldsymbol{G}_{\mathrm{Singer}} = \boldsymbol{G}_{\mathrm{CS}} = \begin{bmatrix} \boldsymbol{I}_{3\times3} & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times3} & \boldsymbol{I}_{3\times3} \end{bmatrix} \otimes \begin{bmatrix} (\alpha\Delta t - 1 + e^{-\alpha\Delta t})/\alpha^2 \\ (1 - e^{-\alpha\Delta t})/\alpha \\ e^{-\alpha\Delta t} \end{bmatrix} \tag{11}$$

$$\boldsymbol{H}_{\mathrm{CV}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$
$$\boldsymbol{H}_{\mathrm{CA}} = \boldsymbol{H}_{\mathrm{Singer}} = \boldsymbol{H}_{\mathrm{CS}} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{12}$$

in which $v_{jx}^t, v_{jy}^t, a_{jx}^t$ and a_{jy}^t are true velocities and accelerations of the vehicle j at time t in x_e and y_e axes; $\hat{v}_{jx}^t, \hat{v}_{jy}^t, \hat{a}_{jx}^t$ and $\hat{a}_{jy}^t$ are estimated values of them, respectively; $\boldsymbol{I}_{2\times2}$ and $\mathbf{0}_{2\times2}$ are 2×2 identity and zero matrix; Δt is the timeslot between $t+1$ and t; α is the reciprocal of the maneuver time constant; $\otimes$ stands for the Kronecker product.

Let $\boldsymbol{Y}^t(k), k = 1,2,$ denote the k^{th} entry of vector $\boldsymbol{Y}^t$. Note that $\boldsymbol{Y}^t(1)$ and $\boldsymbol{Y}^t(2)$are noisy measurements of x_j^t and y_j^t , respectively. As for initial model probability, it is safe to set as $(\mathrm{CV}, \mathrm{CA}, \mathrm{Singer}, \mathrm{CS})' = (0.7, 0.1, 0.1, 0.1)'$ and initial model transition probability matrix as:

$$\mathcal{P}_0 = \begin{bmatrix} 0.91 & 0.03 & 0.03 & 0.03 \\ 0.03 & 0.91 & 0.03 & 0.03 \\ 0.03 & 0.03 & 0.91 & 0.03 \\ 0.03 & 0.03 & 0.03 & 0.91 \end{bmatrix} \tag{13}$$

This is determined from experience. After applying the interactive multiple model with canonical Kalman filter (IMM-KF), the estimated position $\widehat{\boldsymbol{O}}_j^t = (\hat{x}_j^t, \hat{y}_j^t)'$ and velocity $\widehat{\boldsymbol{v}}_j^t = (\hat{v}_{ix}^t, \hat{v}_{iy}^t)$ are computed. Compared with $\boldsymbol{O}_j^t$ that are taken directly from a sensor (j=0) or indirectly from Equation (1) (j > 0), the estimated $\widehat{\boldsymbol{O}}_j^t = (\hat{x}_j^t, \hat{y}_j^t)'$ are more precise. Since IMM-KF is not very sensitive to the initial model probability, arbitrarily assigning a reasonable initial value does not cause a disaster.

The communication logic of system 100 is now presented. Given a train $H - S_{i_{[1]}} \cdots - S_{i_{[n]}}$ and time t, the logic for the trailing vehicle $i_{[j]}$ $(j = \{1, \dots, n\})$ can be determined. At least each trailing vehicle comprises an identifier (i.e., PID or LID). In an embodiment, the PIM on vehicle $i_{[j]}$ first gets its heading θ_j^t and PID $i_{[j]}$. Then the PIM communicates the respective identifier, with the detected motion of the respective second vehicle, to processor 104. It will be appreciated that to detect the heading the PIM actually detects motion using an accelerometer, gyroscope, or other inertial system. Said motion in such cases is used to determine the heading. To be specific, there are two cases:

(a) If the vehicle in question is the last trailing vehicle linked on the train (i.e., $j = n$), PIM sends this information to the associated TAB via RS232 which is a wired channel. The TAB forwards the received to paired BAB on vehicle $i_{[j-1]}$ by the wireless electromagnetic channel. The last trailing vehicle may know its role by receiving either no signals from a nearby TAB, or only heavily delayed signals indicating that the TAB(s) are outside the range to be expected for a further rearward vehicle;

(b) If the vehicle in question is not the last vehicle (i.e., $1 \le j < n$), the PIM on vehicle $i_{[j]}$ gets information $\{(\theta_k^t, i_{[k]}) \mid k = j + 1, \dots, n\}$ from BAB via RS232. Then PIM generates a new message package $\{(\theta_k^t, i_{[k]}) \mid k = j, \dots, n\}$ (which adds the information of itself) and sends to BAB on vehicle $i_{[j-1]}$ similarly as Case (a).

Figure 10 provides a visual illustration and displays the label of each component mentioned in communication logic 120. For the leading vehicle H, the APM first receives headings and PIDs, $\{(\theta_k^t, i_{[k]}) \mid k = 1, \dots, n\}$, of all trailing vehicles from the connected BAB. It also obtains location and heading $(x_0^t, y_0^t, \theta_0^t)$ of the leading vehicle from sensors. Based on them, the APM uses a geometry based positioning algorithm and moving-object tracking algorithm to compute velocities $v_j^t (j = 0, \dots, n)$ and precision-improved locations of the whole train, including the leading vehicle and all trailing vehicles $(\hat{x}_j^t, \hat{y}_j^t)(j = 0, \dots, n)$. Then the real-time position and velocity of each vehicle in the plurality of interconnected vehicles is transmitted to the remote server. In an embodiment, it is the APM that sends the status of the train $\{(\hat{x}_j^t, \hat{y}_j^t, h_j, v_j^t, \theta_j^t) \mid j = 0,1, \dots, n\}$ (h_j is constant and the height of vehicle j) at time period t to the remote server via Internet for higher-level functions like collision detection and optimal scheduling.

The steps of communication logic 120 are shown in Figure 11. Table I details the communication logic of an example train $H - S_{i_{[1]}} - S_{i_{[2]}}$ (i.e., Head-Slave 1-Slave 2 as illustrated in Figure 10) step by step. Note that H , $S_{i_{[1]}}, S_{i_{[2]}}$ each comprises an ID (i.e., physical identifier).

Communication Logic of ROPHS

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1: Note: Arrows define the information streams. The message packages are above arrows, while the communication channels are below arrows. See also Figure 10 for illustration.
2: Initialize: $t \leftarrow 1$
3: repeat
4:     PIM 1013 gets heading $\theta_2^t$ and ID of Slave 2
5:     Send to TAB 1011: PIM 1013 $\xrightarrow[\text{RS232 1012}]{(\theta_2^t, i_{[2]})}$ TAB 1011
6:     Relay to BAB 1009: TAB 1011 $\xrightarrow[\text{UWB channel 1010}]{(\theta_2^t, i_{[2]})}$ BAB 1009
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7:  Forward to PIM 1007: BAB 1009 $\xrightarrow[\text{RS 232 1008}]{(\theta_2^t, i_{[2]})}$ PIM 1007
8:  PIM 1007 gets heading $\theta_1^t$ and ID of Slave 1
9:  Send to TAB 1005: PIM 1007 $\xrightarrow[RS\text{232 1006}]{\{(\theta_j^t, i_{[j]}) | j=1,2\}}$ TAB 1005
10: Relay to BAB 1003: TAB 1005 $\xrightarrow[\text{UWB channel 1004}]{\{(\theta_j^t, i_{[j]}) | j=1,2\}}$ BAB 1003
11: Forward to APM 1001: BAB 1003 $\xrightarrow[\text{RS 232 1002}]{\{(\theta_j^t, i_{[j]}) | j=1,2\}}$ APM 1001
12: APM 1001 obtains $\theta_0^t$, $(x_0^t, y_0^t)$ as well as ID of Head
13: APM 1001 calls positioning algorithm and tracking algorithm to compute velocities $(\hat{v}_0^t, \hat{v}_1^t, \hat{v}_2^t)$ and precision improved locations $\{(\hat{x}_j^t, \hat{y}_j^t) \mid j = 0,1,2\}$
14: Transmit to server: APM 1001 $\xrightarrow[\text{internet}]{\{(\hat{x}_j^t, \hat{y}_j^t, h_j, \hat{v}_j^t, \theta_j^t) | j=0,1,2\}}$ remote server
15: $t \leftarrow t + 1$
16: until $t$ is the last time period
```

Table I

As shown in Figure 11, initially at Step 1102, one or more PIMs of each second vehicle are used to calculate a real-time heading and ID of the respective second vehicle. As illustrated in line 4 of Table I and Figure 10, PIM 1013 gets the real-time heading of Slave 2 by calculating the real-time heading and ID of Slave 1.

The real-time heading and ID of each second vehicle in the train is then accumulated at Step 1104. In particular, a signal comprising the accumulated real-time heading and ID of the initial second vehicle (i.e., Slave 2) is produced first. Then said signal is relayed to each other said second vehicle in series. For example in Figure 10, PIM 1013 sends the heading and ID of Slave 2 to TAB 1011 via the wired RS232 1012 (see line 5, Table I). TAB 1011 is configured to transmit the signal from PIM 1013 to BAB 1009 of the neighbouring one of Slave 2. According to line 6 of Table I, TAB 1011 relays the signal from PIM 1013 to BAB 1009 via the UWB electromagnetic channel (i.e., 1010). Note that TAB 1011 is positioned at a leading end of Slave 2 and BAB 1009 is positioned at a trailing end of Slave 1 (i.e.,

$S_{i_{[1]}}$). Then, as shown in line 7 of Table I, BAB 1009 forwards the message package to PIM 1007 via RS232 1008. That is to say, said signal is relayed from Slave 2 to its neighbouring vehicle in series or sequence (i.e., Slave 1). Note that at Step 1108, said each other second vehicle adds to the signal the real-time heading and ID of the respective second vehicle. In particular, according to line 8 of Table 1, PIM 1007 obtains the real-time heading of Slave 1. Said PIM 1007 at the sixth step (see Table 1, line 9) then combines this new heading information, together with the ID of Slave 1, with the message package from BAB 1009, generates a new message package including two headings and two IDs.

At Step 1106, once all second vehicles have added their respective real-time headings and IDs to the signal, the signal is relayed to the first vehicle. For example, as shown in line 10 of Table I, TAB 1005 of Slave 1 transmits the physical ID for Slave 1 to BAB 1003 of the neighbouring one of Slave 1 (i.e., Head H). In particular, PIM 1007 resends the new message package to BAB 1003, routing as RS232 1006, TAB 1005, and the UWB electromagnetic channel 1004. And then (see line 11, Table I), BAB 1003 delivers the message package to the APM 1001 via the RS232 1002. That is to say, said signal comprising the real-time heading and physical identifier of all second vehicles are finally sent to the first vehicle (i.e., Head H in Figure 10).

At Step 1108, a real-time geolocation and real-time heading of the first vehicle are obtained via the APM, and the vehicle identifier for each vehicle in the plurality of interconnected vehicles is obtained from the signal described with reference to Step 1106. For example, see line 12 of Table I, APM 1001 actively obtains the precise position and heading of the leading vehicle, as well as the ID for H. Then at Step 1110, the geolocation and real-time heading of the first vehicle and the identifier for each vehicle, a real-time position and velocity of each vehicle in the plurality of interconnected vehicles, and a structure of the plurality of the plurality of interconnected vehicles are calculated from the signal. In an embodiment, as shown in line 13 of Table 1, it is APM 1001 that calculates the positions and velocities of all the velocities of the train by using the headings and physical IDs contained in the received message package and the advanced movement-tracking algorithm. In other embodiments, the signal is sent from the APM (also referred to as AM) to a remote server for that calculation.

At Step 1112, the real-time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles are consolidated in a database. In one example, as shown in line 14 of Table 1, APM 1001 transmits the real-time and precise positions, velocities, headings, and the real-time structure (namely the number and the linking sequence) of the train to the remote server via internet for higher-level train scheduling. Note that said linking-sequence comprises the IDs of $H, S_{i_{[1]}}, S_{i_{[2]}}$. It will be appreciated that the proposed communication logic remains similar for the case of more than two trailing vehicles in other examples, and more than one leading or first vehicle. Moreover, the real-time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles can be further adjusted to prevent at least one vehicle from colliding with a further object.

Heading information is generated by the GMA module for leading or trailing vehicles. In some circumstances drift will occur either by accumulated error or physically, particularly for slippery surfaces over which a train travels. Therefore, periodic calibration (reset) is necessary. It is convenient to handle this recalibration under the IMM-KF framework. Specifically, when the CV or CS model is dominant over other models for a relative long time, it is safe to reset the heading of leading vehicle θ_0^t at time t as $\theta_0^t := \arctan\left(\frac{\hat{v}_{0x}}{\hat{v}_{0y}}\right)$. It is noted that this calibration formula is only applicable for the leading vehicle whose j=0. It does not work for trailing vehicles. However, if the train status is calculated with respect to the CV/CS mode for a considerable time, the train will become straight. In this case, for trailing vehicle $j (j > 0)$ at time point t, just let $\theta_j^t := \theta_0^t$. Then headings of trailing vehicles are also calibrated.

An alternative calibration method can also be put forward. Figure 12 denotes an irregular pentagon defined by the structure of a train. The lengths of line sections $\overline{OA}$, $\overline{OB}$, $\overline{AC}$ and $\overline{BD}$ are known. The length of the line section $\overline{CD}$ could be measured by a TAB-BAB pair. The angles $\angle AOC$, $\angle BOD$ and $\angle COD$ could be given by the following sections:

$$\begin{gathered}\angle AOC = \arctan\left(\frac{\overline{AC}}{\overline{OA}}\right)\\ \angle BOD = \arctan\left(\frac{\overline{BD}}{\overline{OB}}\right)\\ \angle COD = \arccos\left(\frac{\overline{CD}^2 - \overline{OC}^2 - \overline{OD}^2}{-2\cdot\overline{OC}\cdot\overline{OD}}\right)\end{gathered} \tag{14}$$

At time t, it will be appreciated that:

$$\Delta\theta_j^t := \theta_j^t - \theta_{j-1}^t = \angle AOC + \angle BOD + \angle COD - \pi \tag{15}$$

The above equation can be used to periodically correct the cumulated error of the digital gyroscope placed on the vehicle j, where $j = 1{,}2$, recursively. Because θ_0^t has already been corrected by $\theta_0^t := \arctan\left(\frac{\hat{v}_{0x}}{\hat{v}_{0y}}\right)$. In summary, by comparing the values kept in the digital gyroscopes with the values calculated by $\theta_0^t := \arctan\left(\frac{\hat{v}_{0x}}{\hat{v}_{0y}}\right)$ and $\Delta\theta_j^t := \theta_j^t - \theta_{j-1}^t = \angle AOC + \angle BOD + \angle COD - \pi$, the faults of the digital gyroscopes can be diagnosed. After identifying the faults induced by the accumulated/cumulative errors, the gyroscope values can be corrected using values calculated from:

$$\theta_0^t := \arctan\left(\frac{\hat{v}_{0x}}{\hat{v}_{0y}}\right) \text{ and } \Delta\theta_j^t := \theta_j^t - \theta_{j-1}^t = \angle AOC + \angle BOD + \angle COD - \pi \tag{16}$$

Gyroscopes are used to obtain the headings of vehicles since $\theta_0^t := \arctan\left(\frac{\hat{v}_{0x}}{\hat{v}_{0y}}\right)$ and $\Delta\theta_j^t := \theta_j^t - \theta_{j-1}^t = \angle AOC + \angle BOD + \angle COD - \pi$ are not consistently reliable – they are influenced by noise. Thus, only the post-processed and reliable values from the two equations are useful. Specifically, the present disclosure can regard the values given by the two equations as measurements, and then use Kalman filtering to de-noise (also known as filter or smooth) the measurements. Further, the filtered data can be used to diagnose and correct the gyroscope values. It will be appreciated that other filtering methods, like Exponential Smoothing, Moving Average method and others can also be used.

Figures 13A and 13B illustrates how processor 104 can determine the number and the linking sequence of the train from each identifier. It will be appreciated that the linking-sequence and the number of vehicles define a structure of the train. Each vehicle comprises a TAB and BAB. As shown in Figure 13A, the TAB is positioned at a leading end of the respective vehicle and the BAB is positioned at a trailing end of the respective vehicle. The TAB of one vehicle transmits the identifier for that vehicle to the BAB of a neighbouring one of said vehicles. The TAB is also configured to transmit the signal from the respective PIM to the BAB of the neighbouring one of said vehicles. Generally, a BAB can sense all TABs within a limited region, for example, a circle with radius of 10 metres centred at the BAB. However, the TAB and BAB pair only with each other when the distance between them is the smallest of all available pairing distances – this may be determined by time-stamping signals or signal attenuation.

Figure 13A shows a train, $H - S_1 - S_2$, and five trailing vehicles around but not linked to the train. Taking the BAB (1202) on S_1 (1204) as an example, it pairs with the closest TAB (1206) on S_2 (1208). The BAB 1202 could simultaneously sense 7 TABs that have been connected by dotted lines in Figure 13A. However, the distance between the BAB 1202 of S_1 (1204) and the TAB 1204 of S_2 (1208) is the smallest. Thus, BAB 1202 and TAB 1204 build a UWB pair. As a consequence, the vehicle S_2 (1208) becomes the "slave" to S_1 (1204). The reasoning is that, in reality, only the paired TAB and BAB are close enough. Note that the vehicle has a relatively large width compared to the distance of a TAB-BAB pair – accordingly, the pair, the front and rear of neighbouring vehicles should be less than the width of either vehicle.

As shown in Figure 13B, for a RUNNING train in a large airport, the fact that only the paired BAB (1202) and TAB (1206) are close enough also holds. If one vehicle follows another vehicle, the distance between those vehicles should be within a known interval. Thus, if the ranged distance between two vehicles falls into the pre-given interval, two vehicles are considered linked together. Once the pairing is established, S_2 1208 is connected to S_1 1204 and a sub-linking sequence $S_1 - S_2$ is generated. When S_1 1204 and S_2 1208 are mechanically linked, TAB 1210 on S_2 is even closer to BAB 1202 on S_1 than TAB 1208 on S_1. This is because the width of trailing vehicle is greater than the width of space between two adjacent vehicles. Even if the train is running at airport, the above rationale still holds. By this wireless ranging mechanism and periodic checks of validity of UWB pairs, the real-time number and linking sequence of the whole train can be identified.

When the BAB-TAB pair is established, this pair can also be used for communication (i.e., information synchronization) between a proceeding vehicle and a preceding vehicle, via the UWB electromagnetic channel. In such cases, the heading information from PIM is transmitted by this UWB electro-magnetic channel to its preceding PIM or APM for data fusion. Since the UWB ranging mechanism is based on SDS-TW-TOA message packages between the UWB pairs, the communication information, containing the heading(s) and identifier(s), could also be coded in the SDS-TW-TOA message packages.

In some proposed embodiments, the UWB ranging and communication pairs are adopted based on the BAB and TAB. However, the UWB ranging and communication pairs in BAB and TAB could be replaced by BLE (Bluetooth Low Energy) 5.0 or later BLE versions, or another near-field or other communication protocol that can function ranging. The focus for pairing is identifying the smallest distance amongst all available ranges to build a pair – thus, the BLE ranging protocol (i.e., iBeacon) could also be considered for lower energy consumption. Although the one time ranging accuracy of BLE is low, usually in the meter-level, the ranging accuracy can be improved with multiple successive range measurements via filtering methods such as Kalman filtering. In field tests, the sampling time of BLE was set to 0.1 seconds and the canonical exponential smoothing method (coefficient: 0.5) is used to de-noise the range measurements. It was found that although the ranging error of the BLE 5.0 is large (error range after filtering: ±0.65m), the linking sequence of trailing vehicles could be correctly identified.

The modules that are recommended to embody a ROPHS system are listed in Table II.

Module	Suggested Model	Produced by	Performances (real field tested)		Business Website
			Accuracy	Precision	
RTK Board	P327	Hemisphere	0	0.7 cm^2 (variance)	www.hemispheregnss.com
GMA	WT101	Wit-motion	0 (calibrated)	0.0025 deg^2 (variance)	www.wit-motion.com/english.php
UWB	DWM1000	Decawave	0 (calibrated)	2.5 cm^2 for ranging (variance)	www.decawave.com
BLE 5.0	HC-42	HC Tech	0 (calibrated)	0.11 m^2 for ranging (variance)	www.hc01.com

Table II

It will be appreciated that many further modifications and permutations of various aspects of the described embodiments are possible. Accordingly, the described aspects are intended to embrace all such alterations, modifications, and variations that fall within the spirit and scope of the appended claims.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word “comprise”, and variations such as “comprises” and “comprising”, will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavor to which this specification relates.

Claims

1. A system for managing one or more objects of a plurality of interconnected objects, the objects including at least one first object and at least one second object, the system comprising:

   an active module (AM) attachable to each first object and adapted to communicate with an external positioning network to detect real time geolocation of the respective first object;

   a processor for receiving a signal from the AM comprising the real time geolocation and determining a real-time heading and velocity of each first object; and

   a collision detection mechanism to prevent at least one said interconnected object from colliding with a further object.

2. The system of claim 1, further comprising at least one passive information module (PIM) attachable to each second object, for detecting motion of the respective second object, the processor being further configured to receive a detected motion from each PIM, and determine a real-time heading for each second object.

3. The system of claim 2, wherein the first object and second objects are arranged in a train, the system further comprising a tag accessory board (TAB) and base accessory board (BAB) for each second object, wherein:

   for each second object, the PIM determines and transmits a signal comprising a heading of the respective second object, via the TAB of the respective second object, to a BAB of another object in the train;

   each second object that receives a signal via its respective BAB appends to the signal, via the respective PIM, its heading and transmits via its TAB the signal comprising the appended heading to a BAB of another object in the train; and

   when the first object receives a signal via its BAB, it sends to a remote server a signal comprising the heading of each object in the train.

4. The system of 2 or 3, wherein the processor is configured to determine a real-time position of each PIM relative to the AM.

5. The system of any one of claims 1 to 4, wherein the processor comprises a remote server configured to receive the signal transmitted from AM and a signal transmitted from each PIM.

6. The system of any one of 1 to 5, wherein the processor further comprises a moving-object tracking algorithm for determining the real time velocity of multiple points on each object.

7. The system of any one of claims 1 to 6, further comprising a data fusion mechanism comprising at least one of a gyroscope, magnetometer and accelerometer, the processor determining the real-time heading and velocity of the first object based on measurements from the data fusion mechanism.

8. The system of any one of claims 1 to 7, wherein at least one said first object is a leading vehicle, and each said second object is a trailing vehicle in a train of interconnected vehicles.

9. The system of any one of claims 1 to 8, wherein the processor is either:

located, in use, on the plurality of interconnected objects; or

located remotely, the AM being configured to communicate wirelessly with the processor.

10. A train comprising:

a system according to any one of claims 1 to 10; and

each first object is a first vehicle and each second object is a second vehicle, wherein the system is attached to said vehicles.

11. The train of claim 10, wherein the AM is attached on a top surface of the first vehicle, and each PIM is attached below a top surface of the respective second vehicle to avoid contact with cargo on the top surface.

12. The train of claim 11, wherein each PIM is attached to an underside of the respective second vehicle.

13. The train of any one of claims 10 to 12, wherein the processor is configured to determine a real time position of one or more points of the vehicles in the train, by the equation:

$$\begin{cases} \boldsymbol{X}_{\mathcal{M}}^{t+1} = \boldsymbol{\Phi}_{\mathcal{M}}\boldsymbol{X}_{\mathcal{M}}^{t} + \boldsymbol{G}_{\mathcal{M}}\boldsymbol{W}^{t} \\ \boldsymbol{Y}^{t} = \boldsymbol{H}_{\mathcal{M}}\boldsymbol{X}_{\mathcal{M}}^{t} + \boldsymbol{V}^{t} \end{cases}$$

the terms of which are described herein.

14. The train of claim 13, wherein the processor is configured to apply a moving-object tracking algorithm implementing Kalman filtering, to determine a real-time velocity of a point of interest on the train.

15. The train of any one of claims 10 to 14, wherein at least each second vehicle comprises an identifier, each PIM communicating the respective identifier, with the detected motion of the respective second vehicle, to the processor.

16. The train of claim 15, wherein the processor is configured to determine a linking-sequence of vehicles in the train from each identifier, whereby the linking-sequence and a number of vehicles define a structure of the train.

17. The train of claim 15 or 16, wherein each second vehicle comprising an identifier further comprises a tag accessory board (TAB) and each vehicle comprises a base accessory board (BAB) the TAB of one vehicle transmitting the identifier for that vehicle to the BAB of a neighbouring one of said vehicles.

18. The train of claim 17, wherein the TAB is positioned at a leading end of the respective vehicle and the BAB is positioned at a trailing end of the respective vehicle.

19. The train of claim 17 or 18, wherein the TAB is further configured to transmit the signal from the respective PIM to the BAB of the neighbouring one of said vehicles.

20. The train of any one of claims 17 to 19, wherein the first vehicle comprises an identifier, the AM being configured to transmit to a remote server a linking-sequence comprising the identifiers of the first vehicle and second vehicles in an order determined based on a signal received by the BAB of the first vehicle.

21. The train of any one of claims 10 to 20, wherein each AM and PIM comprises a data fusion mechanism comprising at least one of a gyroscope, magnetometer and accelerometer.

22. A method of managing one or more vehicles of a plurality of interconnected vehicles, including:

    at least one first vehicle with an active module (AM) attached thereto; and
    at least one second vehicle, each said second vehicle comprising:
        at least one passive information module (PIM);
        a tag accessory board (TAB);
        a base accessory board (BAB); and
        a physical identifier,
    the method comprising:
        calculating, using the one or more PIMs of each second vehicle, a real-time heading of the respective second vehicle;

accumulating the real-time heading and identifier of each second vehicle in the train:

by producing a signal at an initial said second vehicle, the signal comprising the real time heading and physical identifier of the initial second vehicle; and

relaying the signal to each other said second vehicle in series, each other second vehicle adding to the signal the real-time heading and physical identifier of the respective second vehicle;

relaying the signal the first vehicle, once all second vehicles have added the respective real-time heading and physical identifier to the signal; and

obtaining, via the AM, a real time geolocation and real-time heading of the first vehicle, and a vehicle identifier for each vehicle in the plurality of interconnected vehicles;

calculating, from the signal, the geolocation and real-time heading of the first vehicle and the identifier for each vehicle, a real-time position and velocity of each vehicle in the plurality of interconnected vehicles, and a structure of the plurality of interconnected vehicles;

consolidating the real time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles in a database,

adjusting the real time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles to prevent at least one vehicle from colliding with a further object.

23. The method of claim 22, wherein calculating the real time position and velocity of each vehicle in the plurality of interconnected vehicles comprises calculating, at the first vehicle, the real time position and velocity of each vehicle in the train from the signal, the real time geolocation and real-time heading of the first vehicle.

24. The method of claim 22, wherein the real time position and velocity of each vehicle in the plurality of interconnected vehicles is transmitted to a remote server.

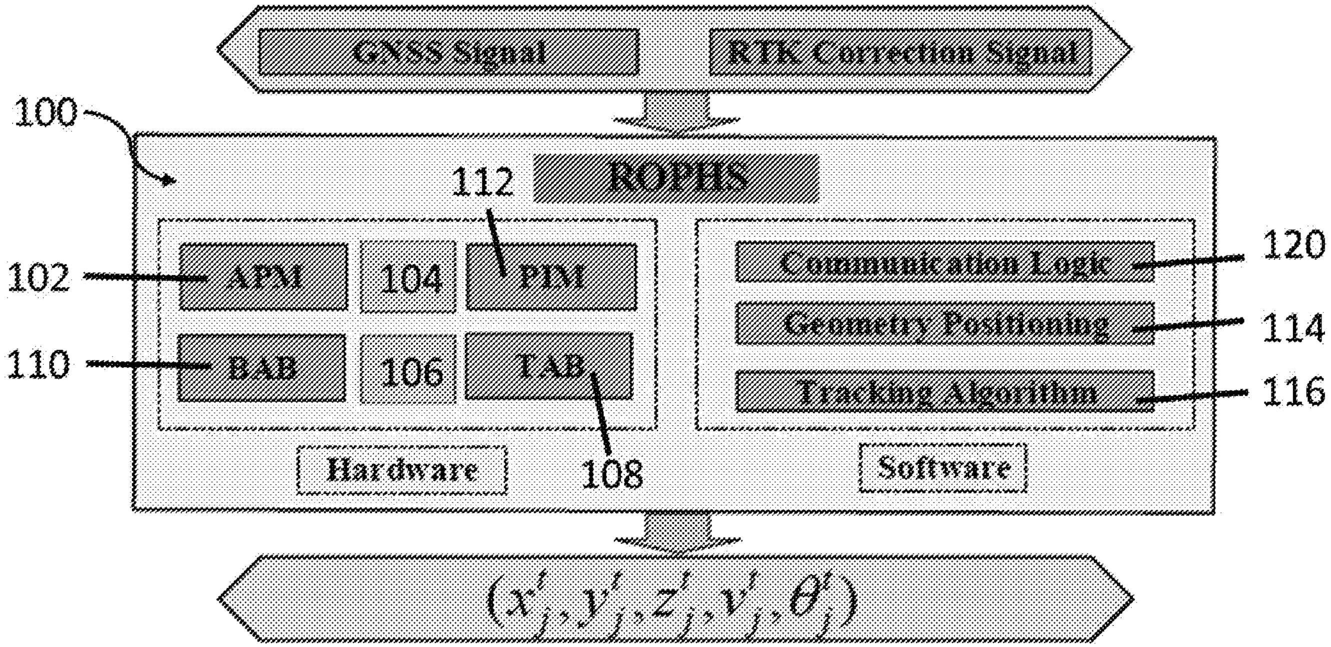

GNSS Signal
RTK Correction Signal
100
ROPHS
112
102
APM
104
PIM
110
BAB
106
TAB
108
Hardware
Communication Logic
120
Geometry Positioning
114
Tracking Algorithm
116
Software
$(x_j^t, y_j^t, z_j^t, v_j^t, \theta_j^t)$

Figure 1

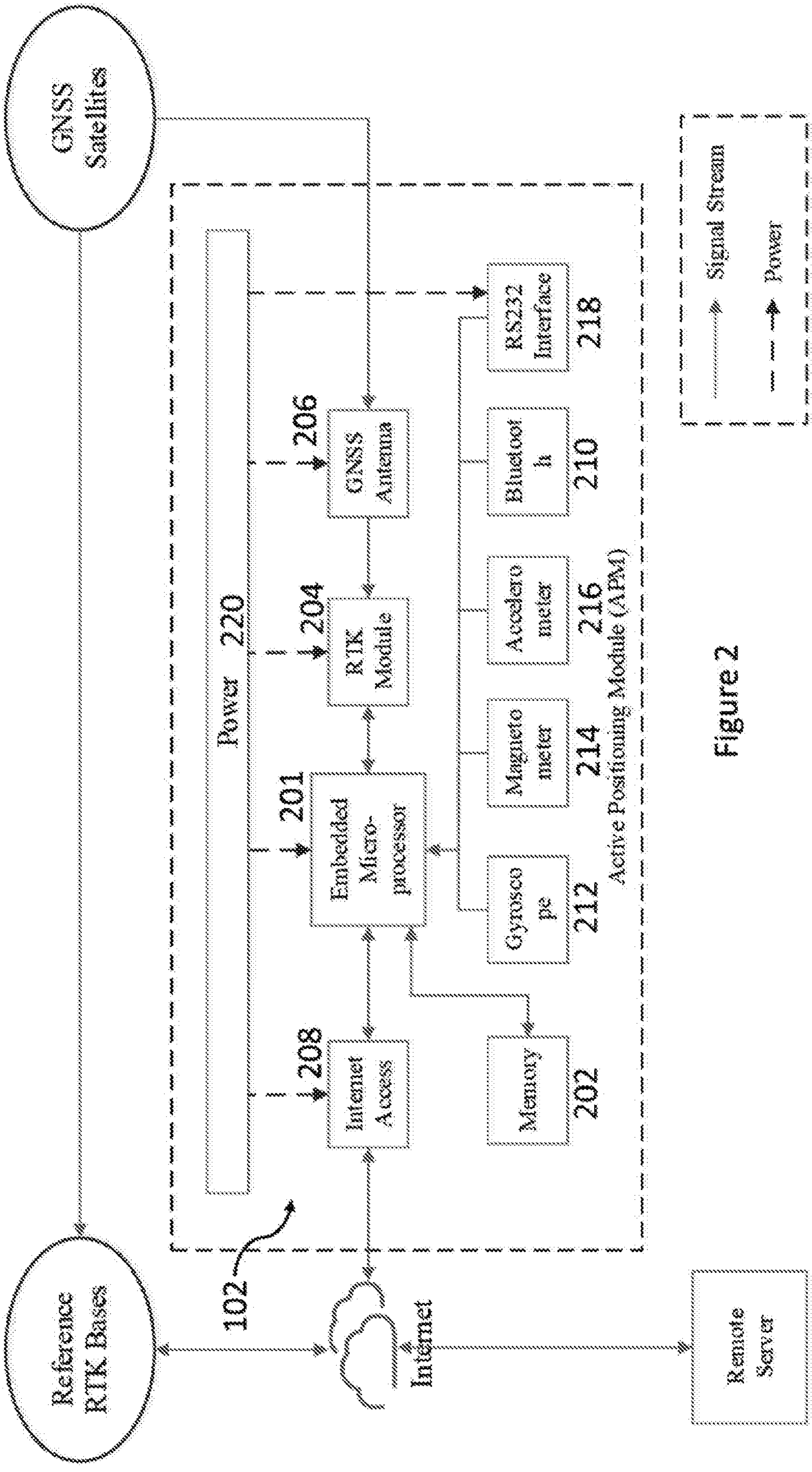

GNSS Satellites
Reference RTK Bases
Internet
Remote Server
102
Power 220
208
Internet Access
201
Embedded Micro-processor
204
RTK Module
206
GNSS Antenna
Memory 202
Gyroscope 212
Magnetometer 214
Accelerometer 216
Bluetooth 210
RS232 Interface 218
Active Positioning Module (APM)
Signal Stream
Power

Figure 2

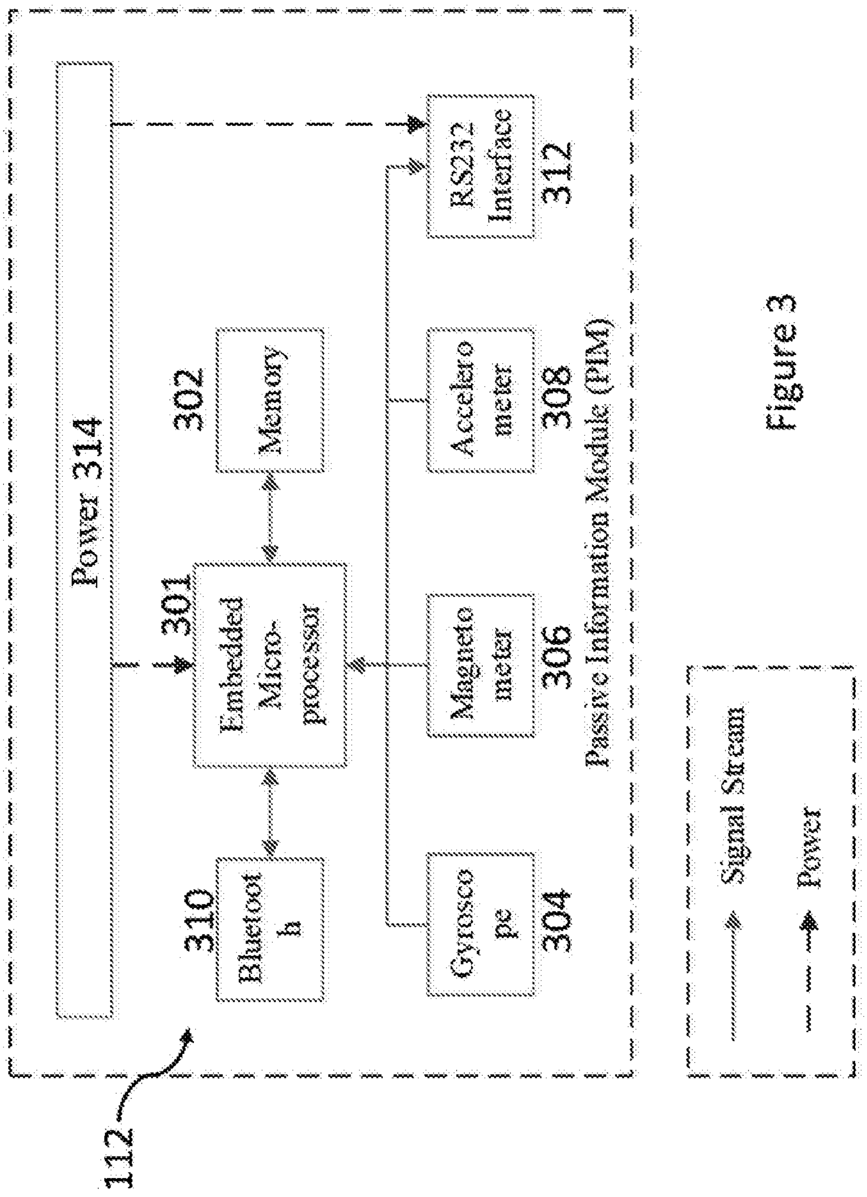

Power 314
310
Bluetoot
h
301
Embedded
Micro-
processor
302
Memory
Gyrosco
pe
304
Magneto
meter
306
Accelero
meter
308
RS232
Interface
312
Passive Information Module (PIM)
112
Signal Stream
Power

Figure 3

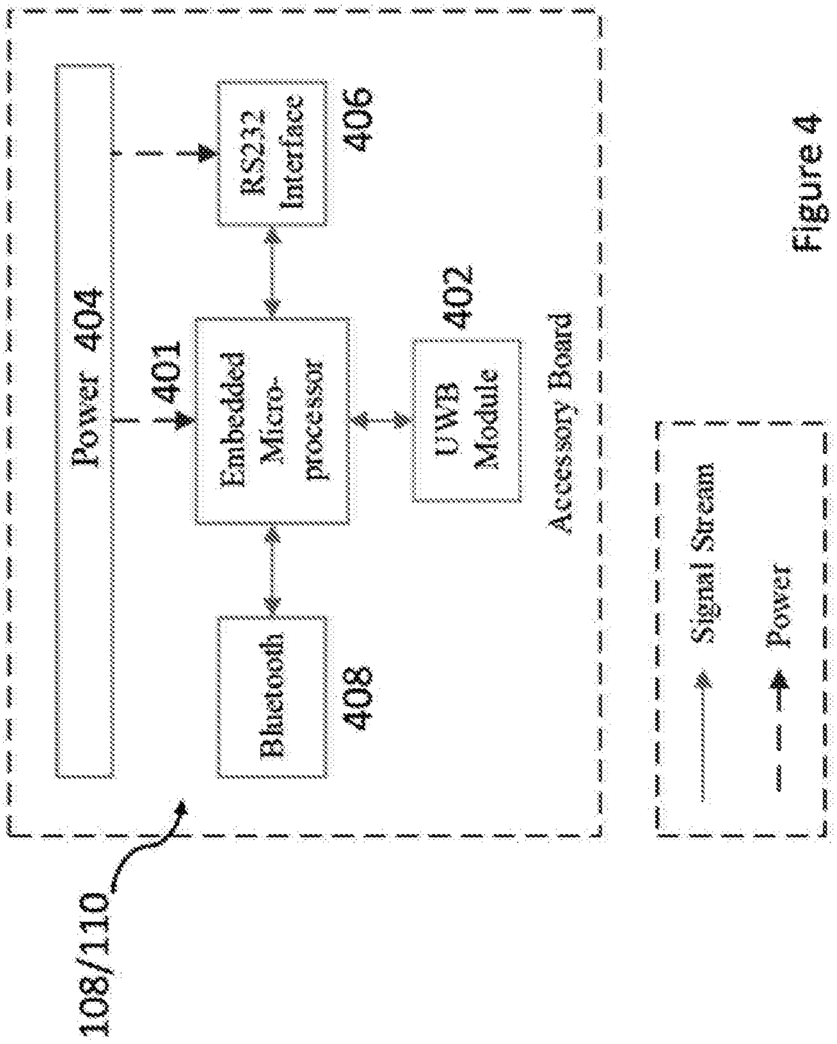
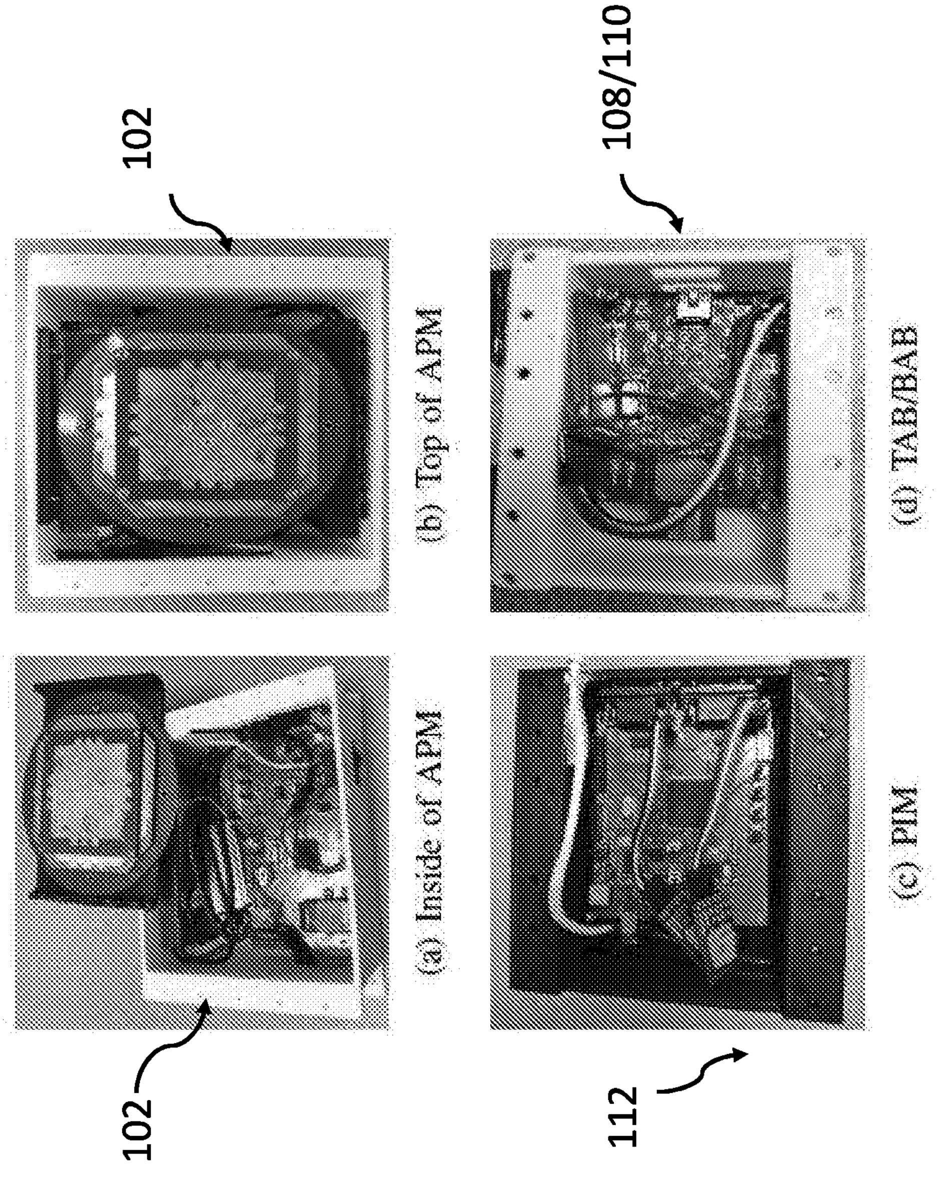

108/110
Power 404
401
Embedded Micro-processor
RS232 Interface
406
UWB Module
402
Bluetooth
408
Accessory Board
Signal Stream
Power

Figure 4



(a) Inside of APM

(b) Top of APM

(c) PIM

(d) TAB/BAB

Figure 5

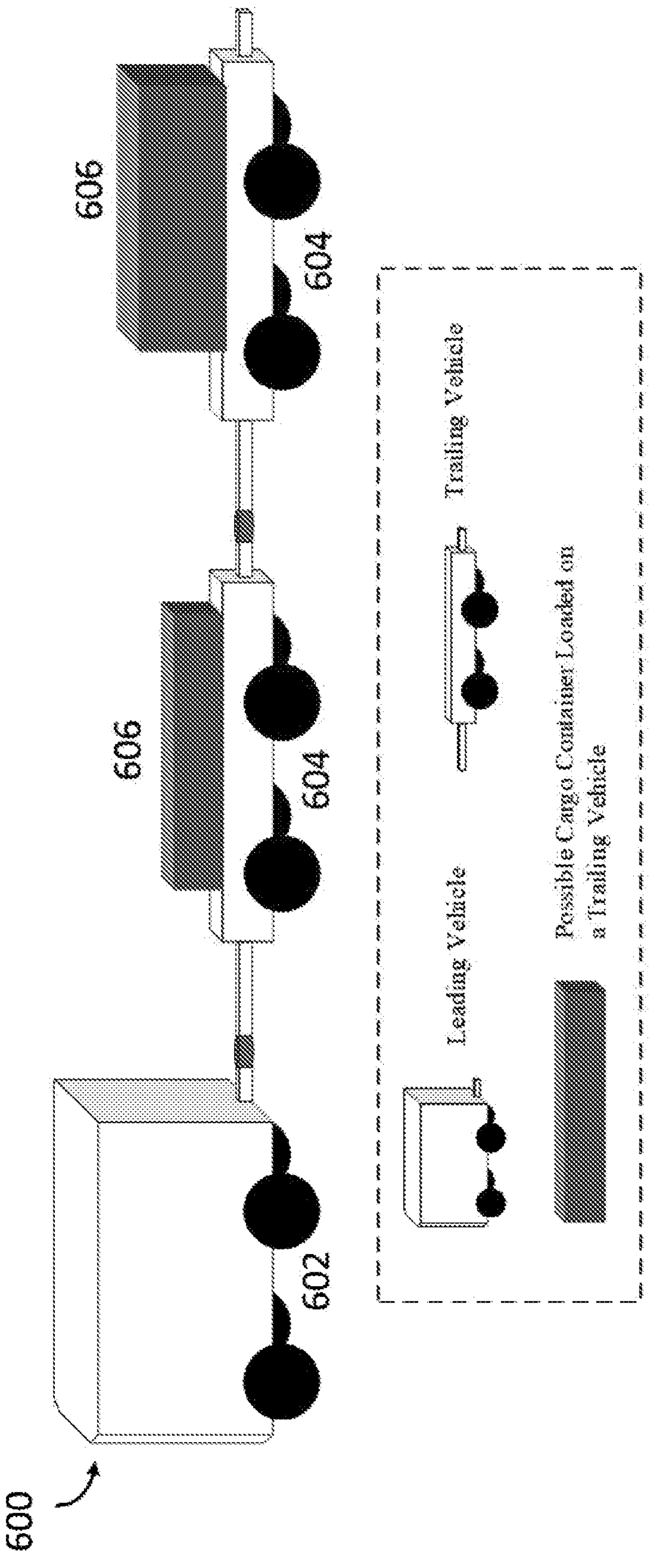

600
602
604
606
604
606
Leading Vehicle
Trailing Vehicle
Possible Cargo Container Loaded on a Trailing Vehicle

Figure 6

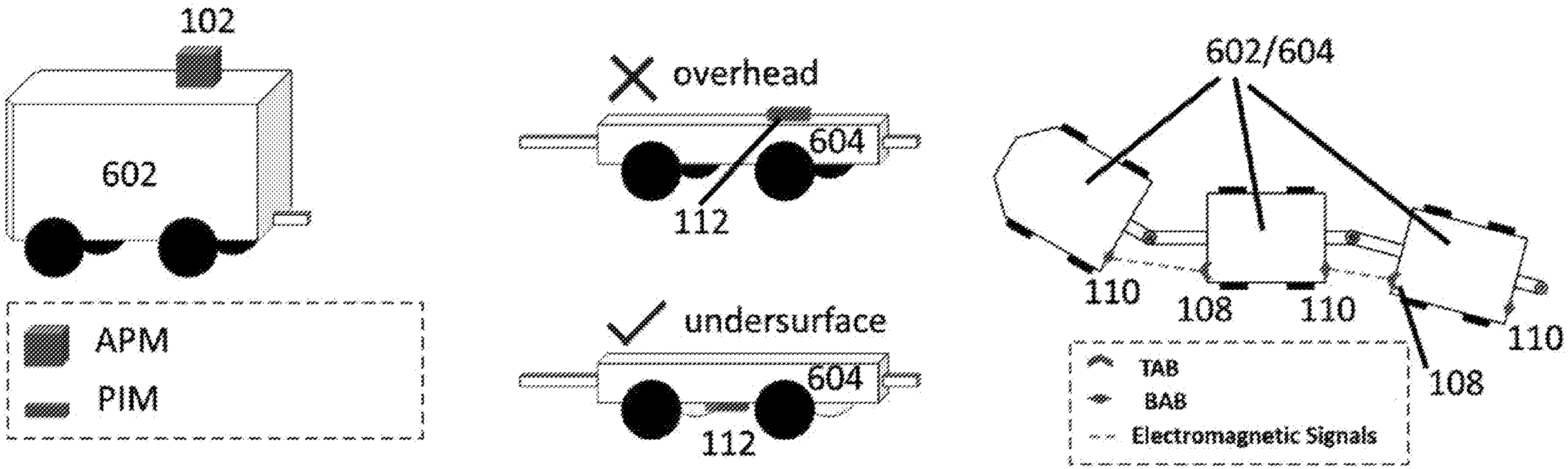


Figure 7A

Figure 7B

Figure 7C

Figure 7

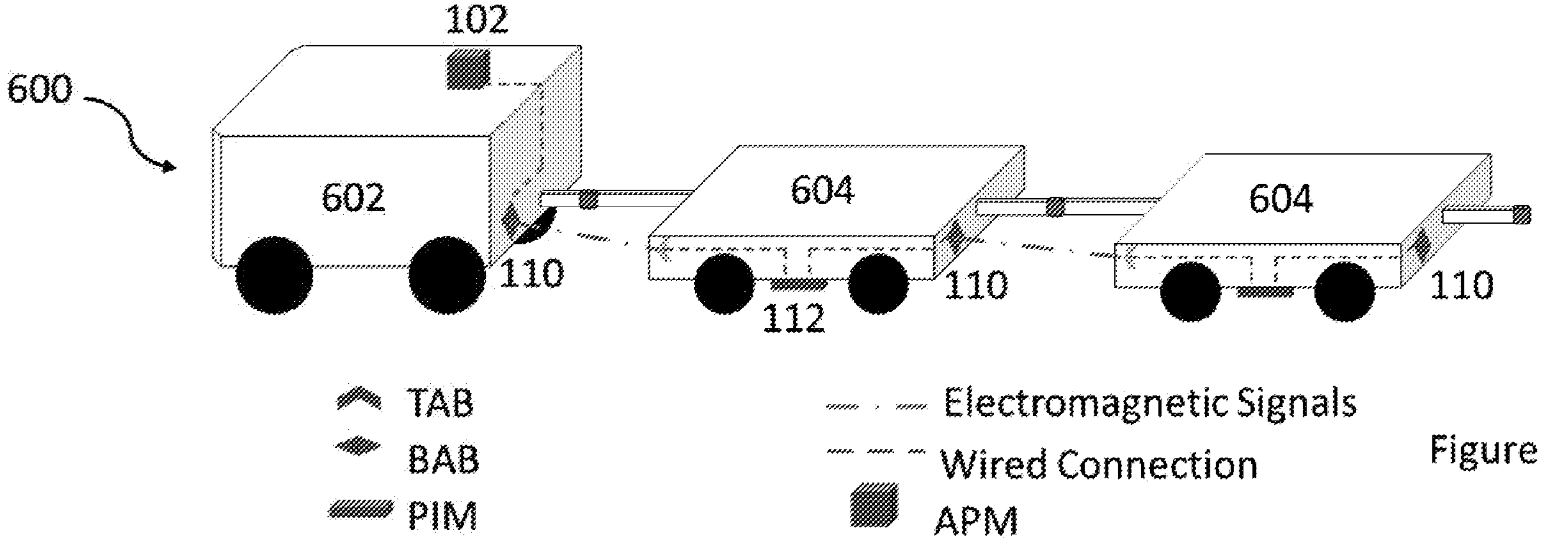


Figure 8A

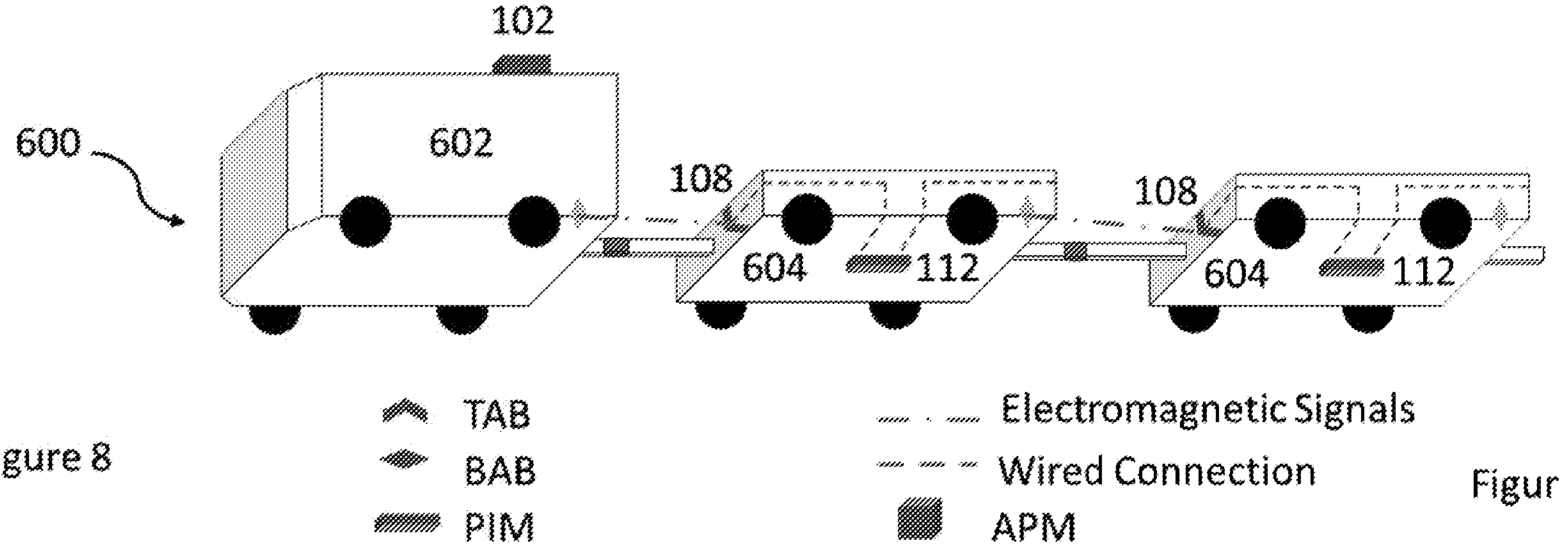


Figure 8B

Figure 8

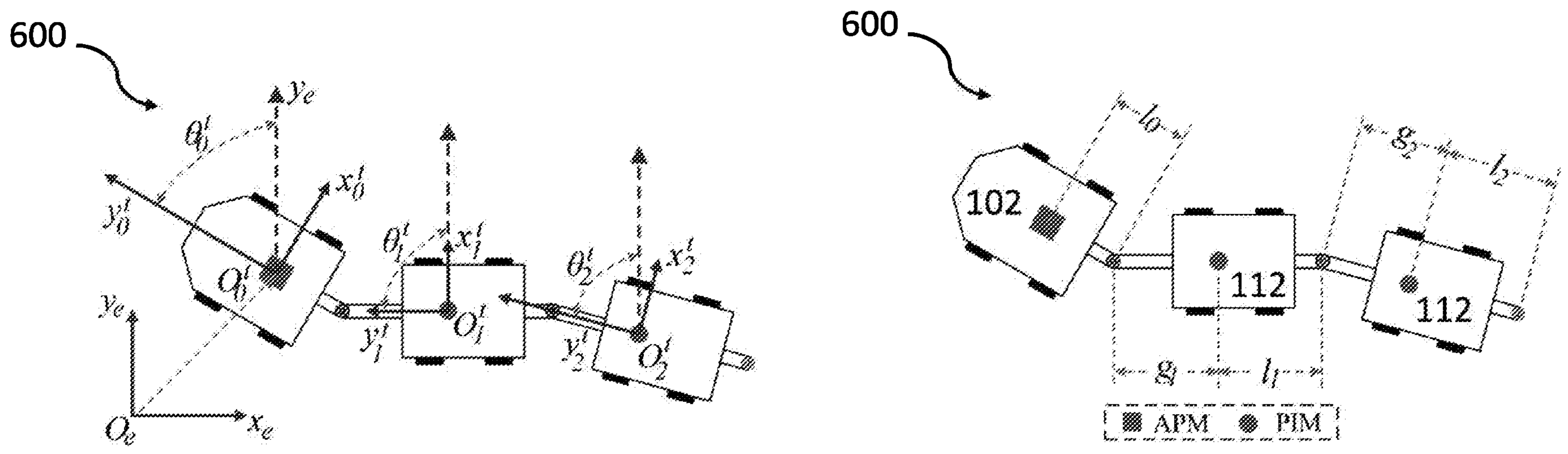


Figure 9A

Figure 9B

Figure 9

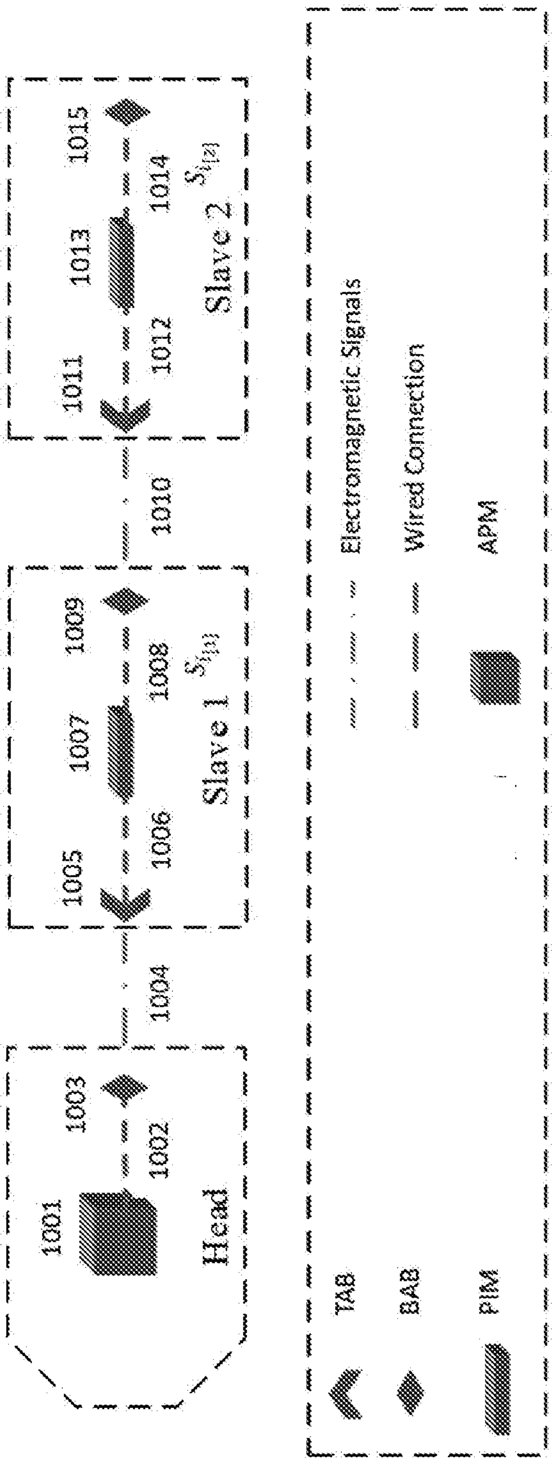
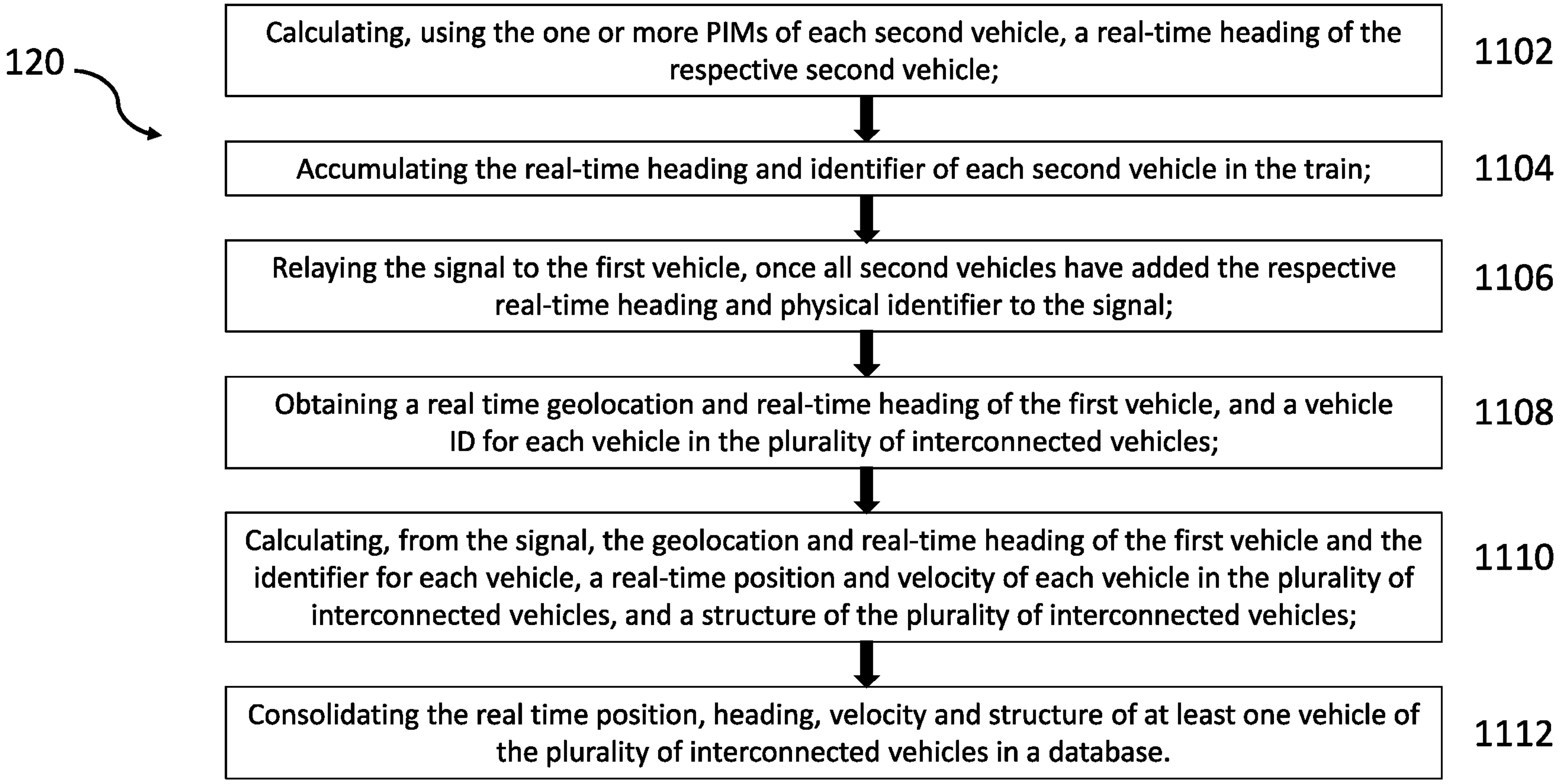

Head
1001
1002
1003
1004
Slave 1
1005
1006
1007
1008
1009
$S_{t[1]}$
1010
Slave 2
1011
1012
1013
1014
1015
$S_{t[2]}$
TAB
BAB
PIM
Electromagnetic Signals
Wired Connection
APM

Figure 10



1102 Calculating, using the one or more PIMs of each second vehicle, a real-time heading of the respective second vehicle;

1104 Accumulating the real-time heading and identifier of each second vehicle in the train;

1106 Relaying the signal to the first vehicle, once all second vehicles have added the respective real-time heading and physical identifier to the signal;

1108 Obtaining a real time geolocation and real-time heading of the first vehicle, and a vehicle ID for each vehicle in the plurality of interconnected vehicles;

1110 Calculating, from the signal, the geolocation and real-time heading of the first vehicle and the identifier for each vehicle, a real-time position and velocity of each vehicle in the plurality of interconnected vehicles, and a structure of the plurality of interconnected vehicles;

1112 Consolidating the real time position, heading, velocity and structure of at least one vehicle of the plurality of interconnected vehicles in a database.

Figure 11

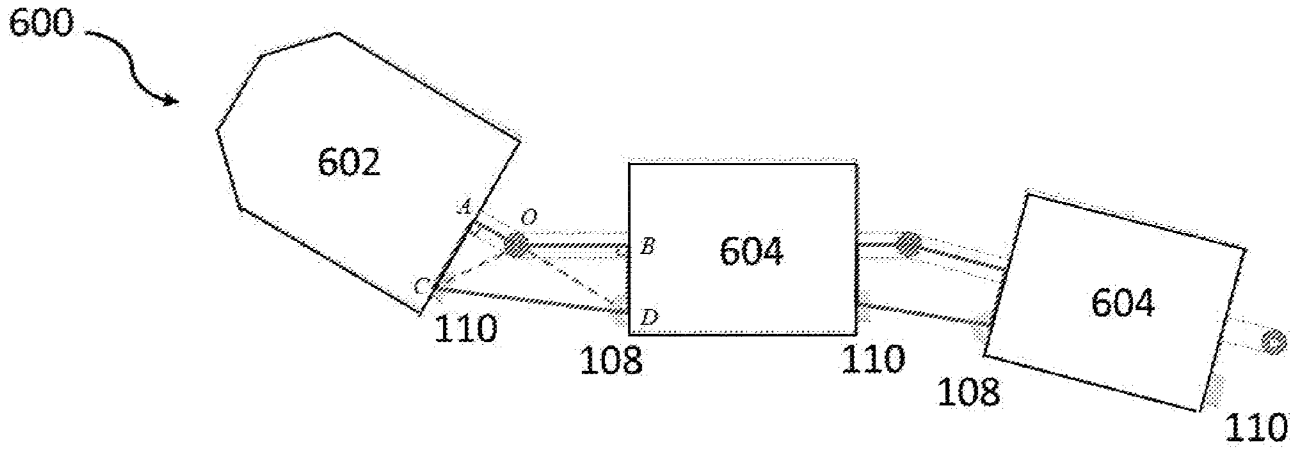


Figure 12

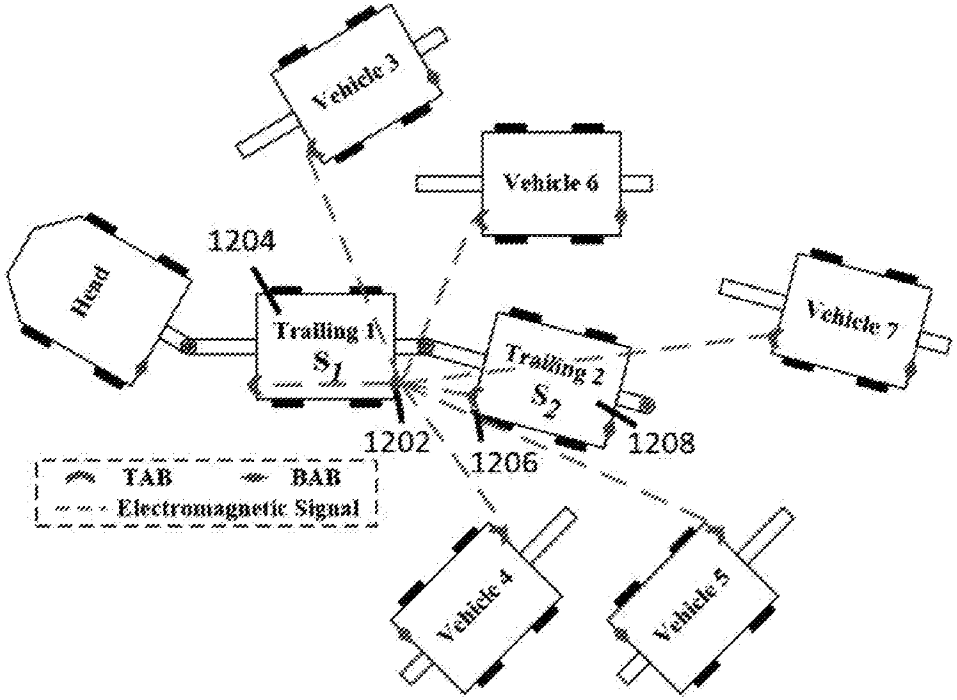


Figure 13A

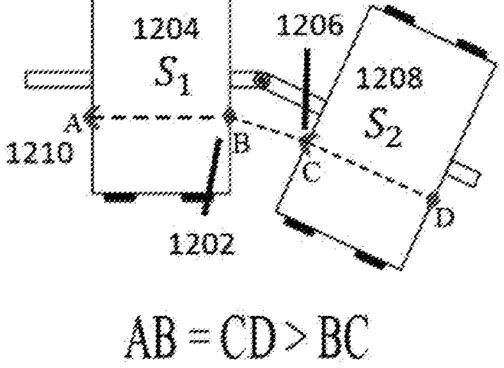


Figure 13B

Figure 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2021/050101

A. CLASSIFICATION OF SUBJECT MATTER

G05D 1/02 (2020.01) ***G01C 23/00 (2006.01)*** *H04W 4/80 (2018.01)* *G01S 5/02 (2010.01)*

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G05D; G01C; H04W; G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

FamPat and Internet: tractor, trailer, dolly, cart, cargo, leading, trailing, towing, towed, vehicle, object, link, connect, couple, semi-tractor, semi-trailer, collision, crash, avoidance, detection, mitigation, anti-collision, GNSS, GPS, geolocation, coordinate, speed, velocity, heading, direction, orientation, sensor, gyroscope, magnetometer, accelerometer, GMA, relay, RFID, UWB, Bluetooth, BLE, beacon, 主车, 牵引车, 挂车, 拖车, 防撞, 碰撞, 冲撞, 方向, 朝向, 速度, 速率, 地理位置, 坐标, 超宽频, 蓝牙, 近场, 射频, 识别, 信标 and the related terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019/0265714 A1 (BALL J. E. ET AL.) 29 August 2019 Figs. 1, 3-4 and para. [0064], [0072]-[0073], [0078], [0089]	1-2, 4-16, 21
X	US 2019/0064835 A1 (HOOFARD R. K. ET AL.) 28 February 2019 Paras. [0049]-[0050], [0055]-[0056], [0064], [0095]	1-2, 4-16, 21
X	CN 105539435 A (WEICHAI POWER) 4 May 2016 Fig. 1 and paras. [0003]-[0004], [0040]-[0048], [0050] of the original non-English language document (a machine translation is enclosed **only** for your reference)	1-2, 4-16, 21
A	US 2007/0288294 A1 (OLSEN J. A. III ET AL.) 13 December 2007 Fig. 3 and para. [0036]	

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 28/04/2021 *(day/month/year)*	Date of mailing of the international search report *05/05/2021* *(day/month/year)*
Name and mailing address of the ISA/SG **Intellectual Property Office of Singapore** 1 Paya Lebar Link, #11-03 PLQ 1, Paya Lebar Quarter Singapore 408533 Email: pct@ipos.gov.sg	Authorized officer Yu Yang (Dr) IPOS Customer Service Tel. No.: (+65) 6339 8616

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2021/050101

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2019/0265714 A1	29/08/2019	WO 2019/165409 A1 CA 3090668 A1 JP 2021509381 A EP 3758983 A1 CN 111757822 A	29/08/2019 29/08/2019 25/03/2021 06/01/2021 09/10/2020
US 2019/0064835 A1	28/02/2019	WO 2019/042958 A1 EP 3676770 A1	07/03/2019 08/07/2020
CN 105539435 A	04/05/2016	NONE	
US 2007/0288294 A1	13/12/2007	JP 2008506608 A EP 1942453 A2 WO 2006/019418 A2 US 2006/0011721 A1 CN 101014950 A CA 2738689 A1 CA 2572956 A1 EP 1782249 A2	06/03/2008 09/07/2008 23/02/2006 19/01/2006 08/08/2007 23/02/2006 23/02/2006 09/05/2007