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(54) **METHODS AND SYSTEMS FOR VIRTUAL TRIP STOPS IN TRAIN NETWORKS**

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(71) Applicant: **Metrom Rail, LLC**, Crystal Lake, IL (US)

(57) **ABSTRACT**

(72) Inventors: **Richard C. Carlson**, Manchester-by-the-sea, MA (US); **Kurt A. Gunther**, Woodstock, IL (US)

Systems and methods are provided for virtual trip stops in train networks. The rail network includes one or more wayside control units configured for deployment on or near tracks in the rail network, with each wayside control unit coupled or attached to a train signal, and the train-based control unit is configured to communicate with any wayside control unit that comes within communication range of the train-based control unit, determine based on processing of communicated signals with at least one wayside control unit one or both of operation information relating to one or both of the at least one wayside control unit and the train and state information relating to a state of train signal, and generate based on the operation information and the state information, control information configured for use in controlling one or more functions of the train in conjunction with operation in the rail network.

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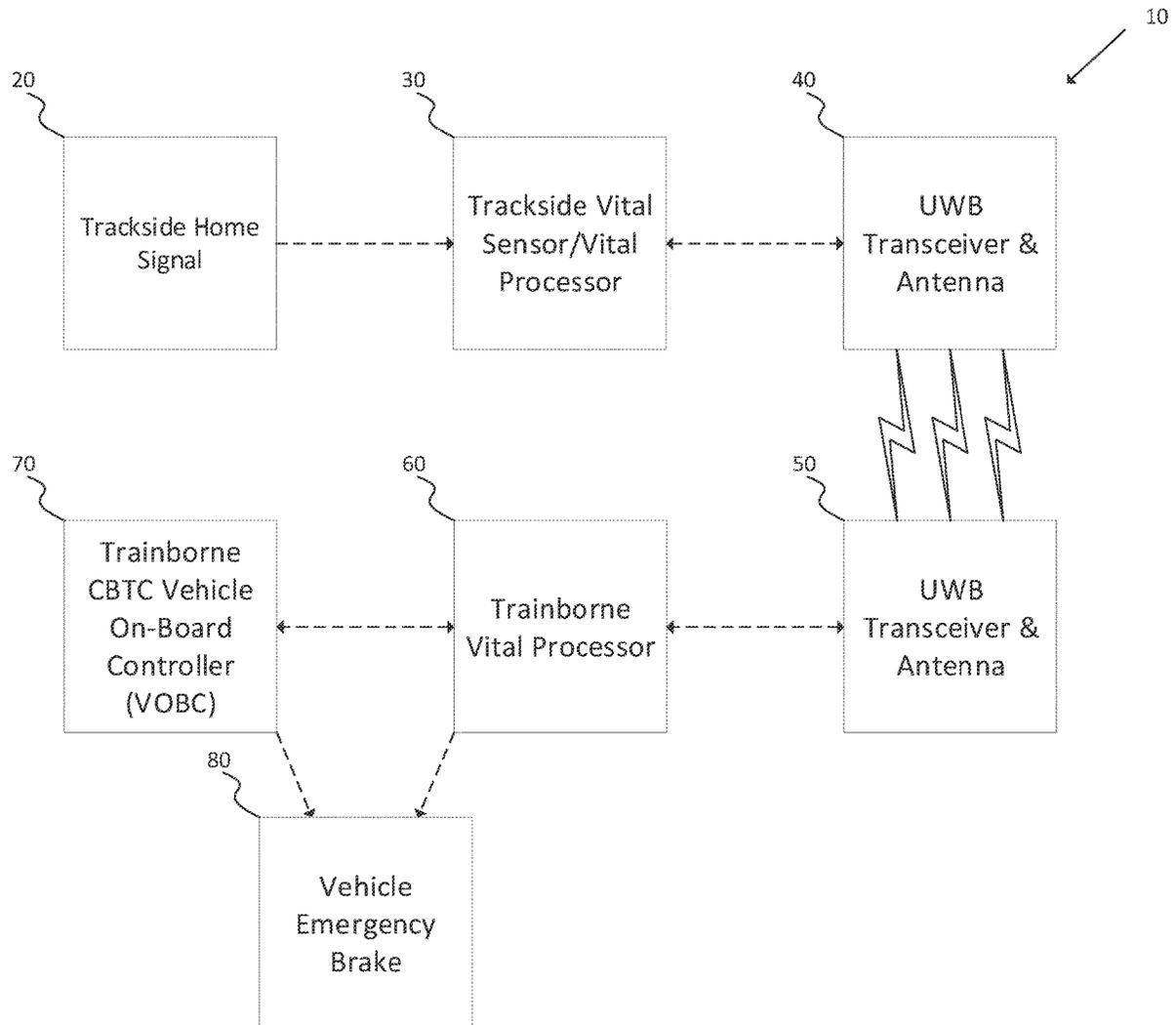
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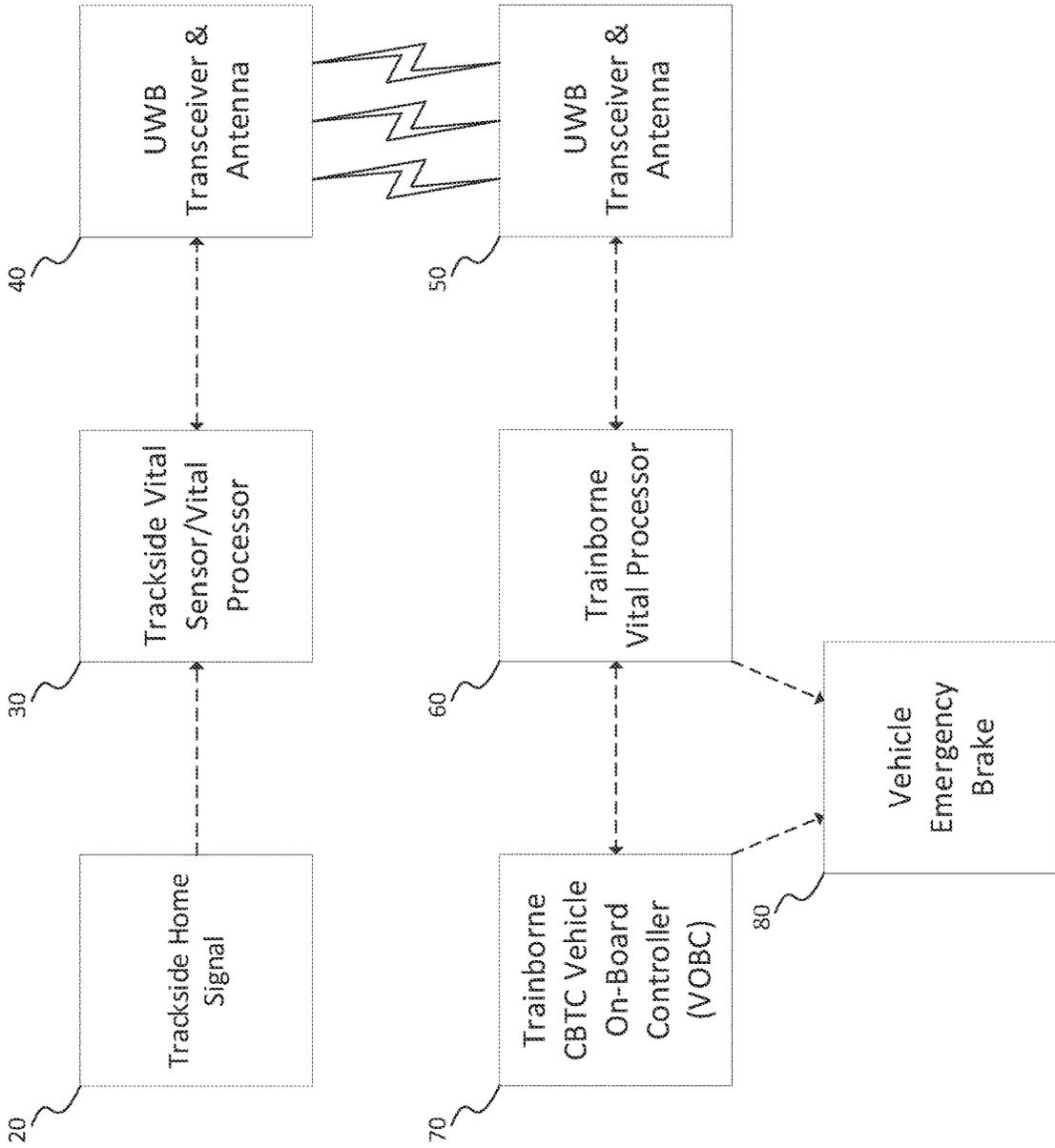


FIGURE 2

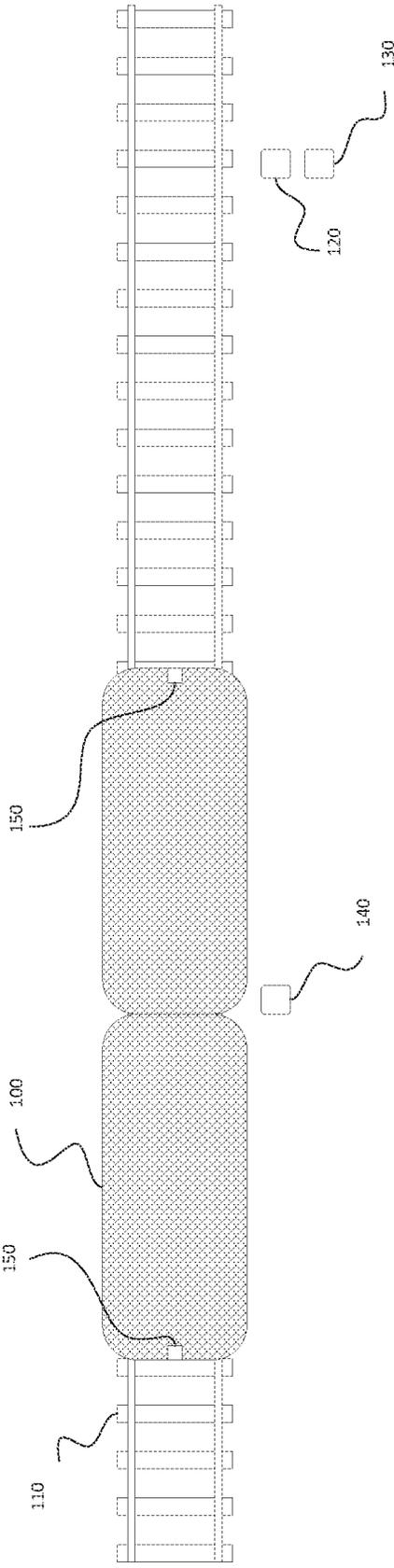


FIGURE 3

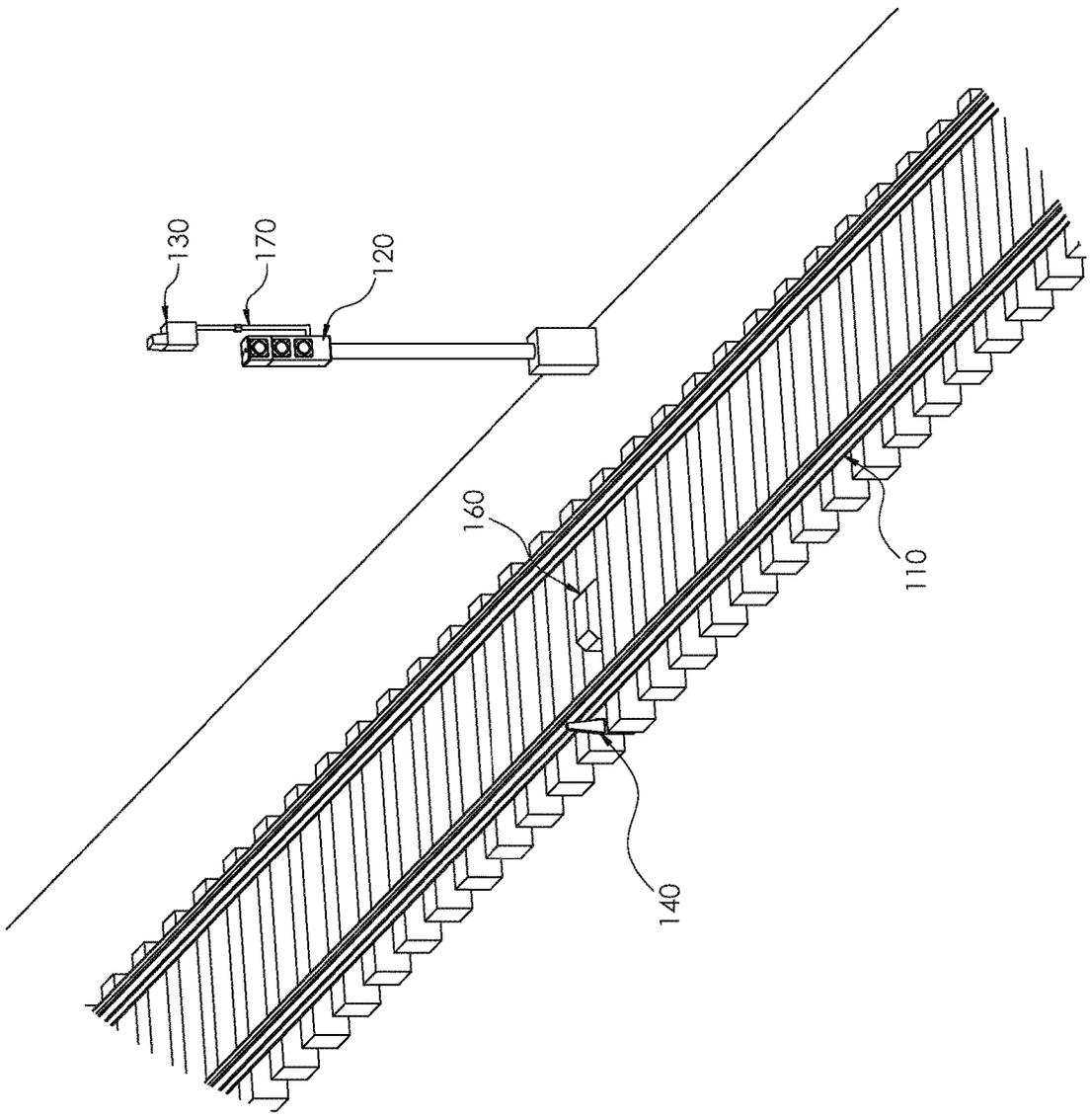


FIGURE 4

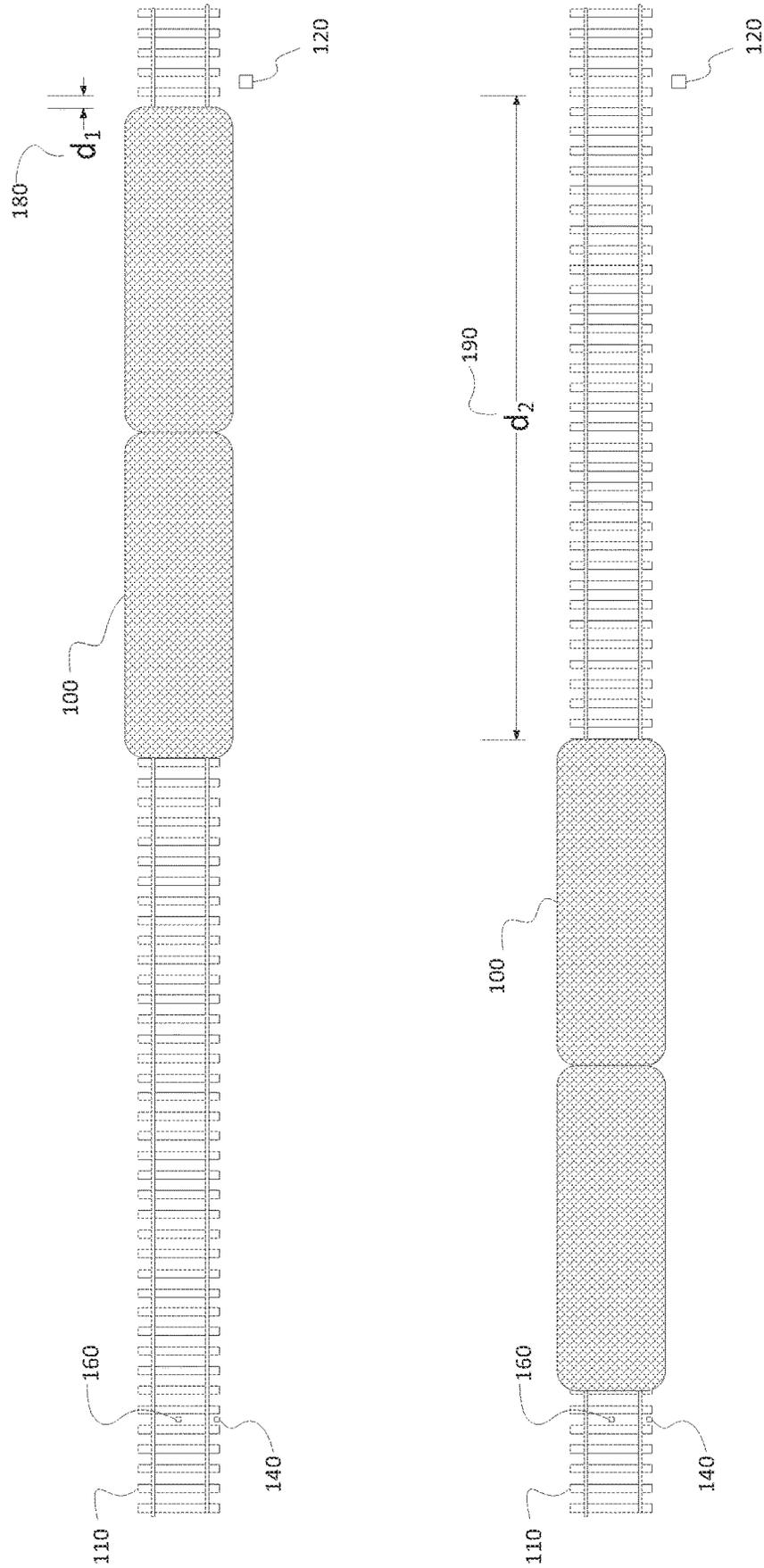
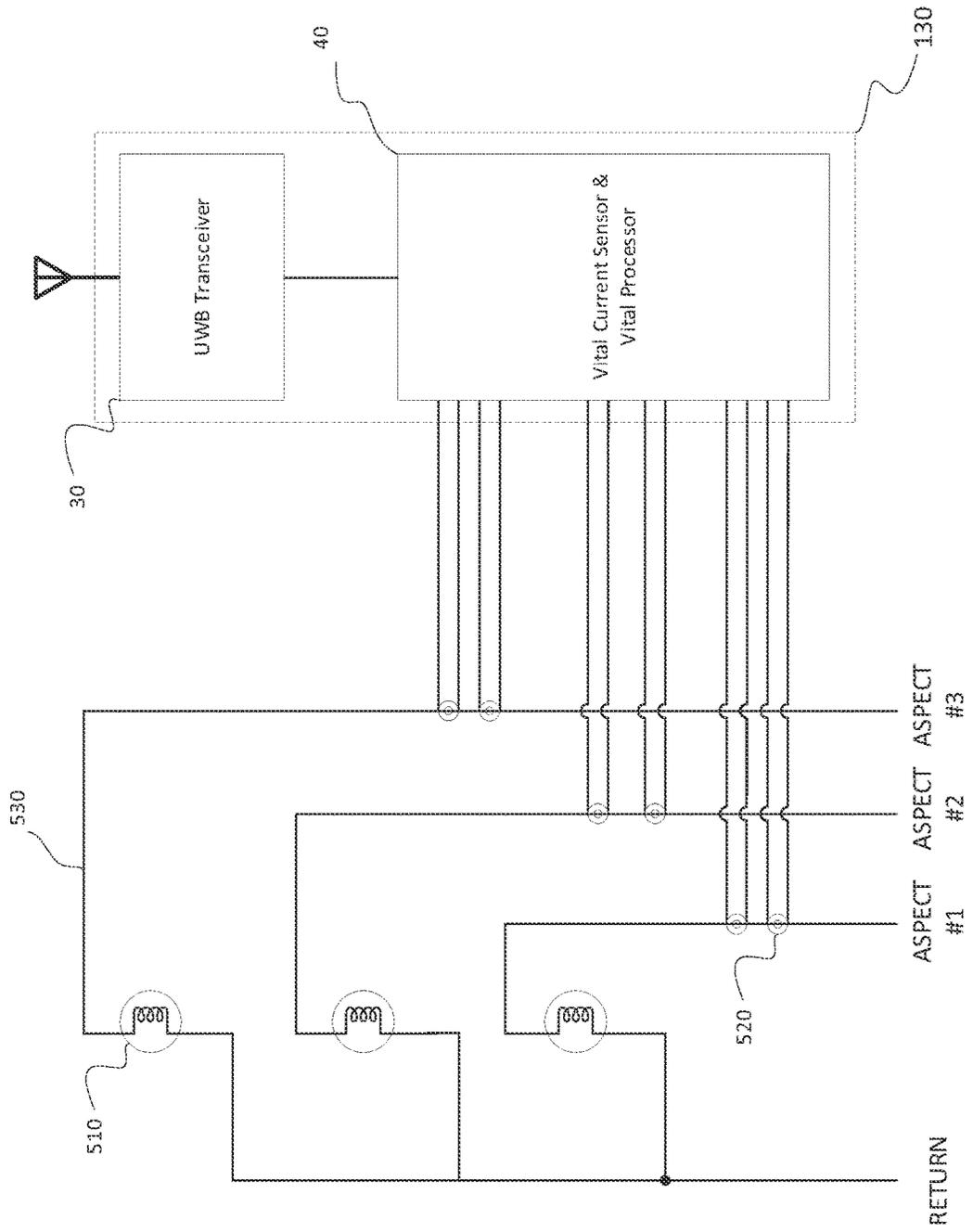
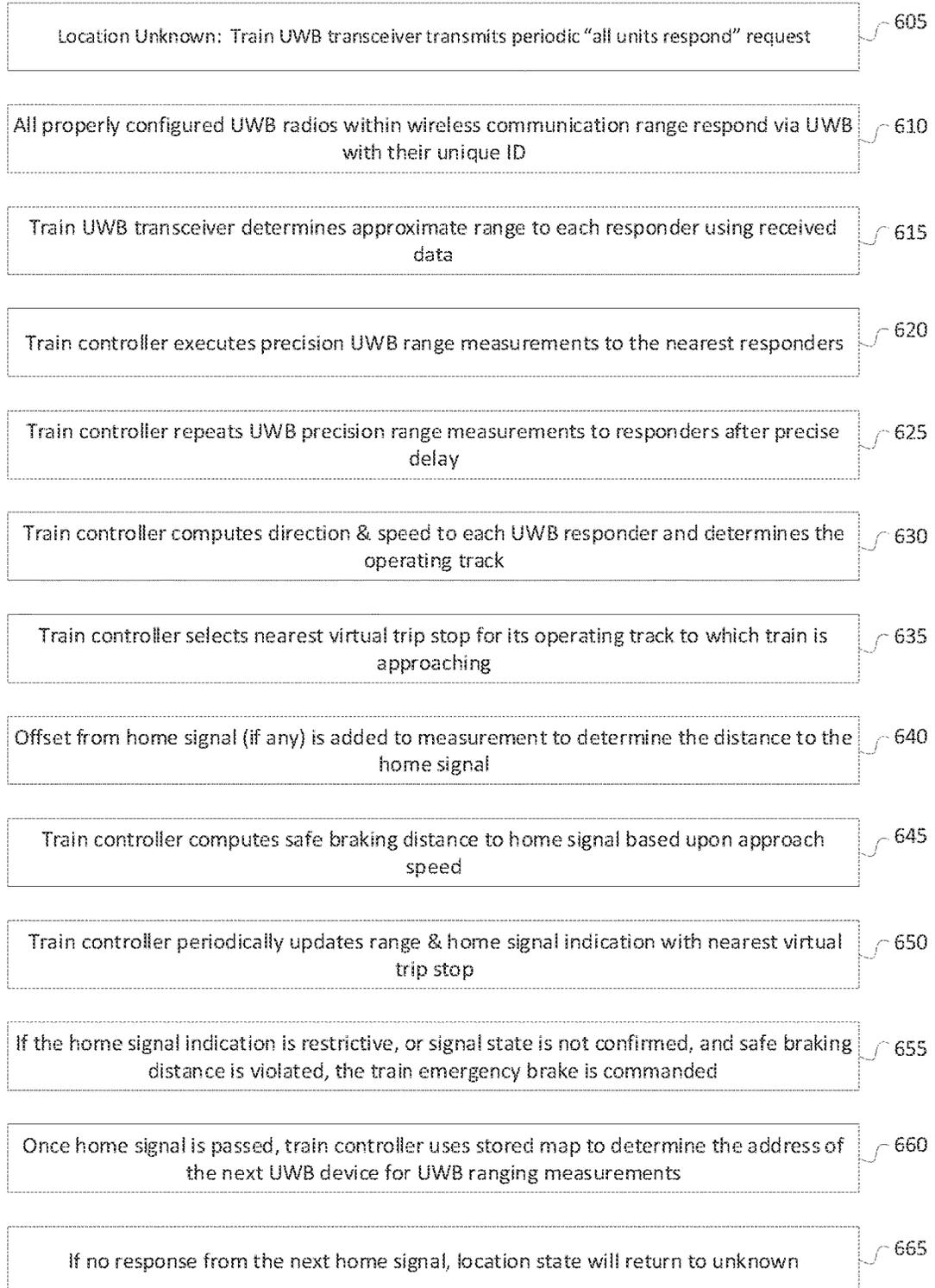


FIGURE 5



600 ↘

FIGURE 6



METHODS AND SYSTEMS FOR VIRTUAL TRIP STOPS IN TRAIN NETWORKS

CLAIM OF PRIORITY

[0001] This patent application makes reference to, claims priority to, and claims benefit from U.S. Provisional Patent Application No. 62/958,114, filed on Jan. 7, 2020. The above identified applications is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to control solutions for use in train systems. More specifically, various implementations of the present disclosure relate to methods and systems for facilitating and implementing virtual trip stops in train networks.

BACKGROUND

[0003] Various issues may exist with conventional train control solutions. In this regard, conventional systems and methods, if any existed, for facilitating and/or managing trip stops in railway systems, may be costly (e.g., to install and maintain), inefficient, and/or ineffective.

[0004] Further limitations and disadvantages of conventional and traditional approaches will become apparent to one of skill in the art, through comparison of such approaches with some aspects of various example methods and systems as set forth in the remainder of this disclosure with reference to the drawings.

BRIEF SUMMARY

[0005] System and methods are provided for virtual trip stops in train networks, substantially as shown in and/or described in connection with at least one of the figures, as set forth more completely in the claims.

[0006] These and other advantages, aspects and novel features of the present disclosure, as well as details of an illustrated embodiment thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 illustrates an example virtual trip stop system, in accordance with the present disclosure.

[0008] FIG. 2 illustrates an example deployment of virtual trip stop system in a rail network, in accordance with the present disclosure.

[0009] FIG. 3 illustrates an example home signal incorporating virtual trip stop related components, in accordance with the present disclosure.

[0010] FIG. 4 illustrates example use scenarios comparing conventional trip stop and virtual trip stop in a rail network.

[0011] FIG. 5 illustrates an example implementation of a home signal with fail-safe sensing, in accordance with the present disclosure.

[0012] FIG. 6 illustrates a flowchart of an example process for enforcing rail vehicle adherence to a home signal using a virtual trip stop, in accordance with the present disclosure.

DETAILED DESCRIPTION

[0013] As utilized herein the terms “circuits” and “circuitry” refer to physical electronic components (e.g., hardware), and any software and/or firmware (“code”) that may

configure the hardware, be executed by the hardware, and or otherwise be associated with the hardware. As used herein, for example, a particular processor and memory (e.g., a volatile or non-volatile memory device, a general computer-readable medium, etc.) may comprise a first “circuit” when executing a first one or more lines of code and may comprise a second “circuit” when executing a second one or more lines of code. Additionally, a circuit may comprise analog and/or digital circuitry. Such circuitry may, for example, operate on analog and/or digital signals. It should be understood that a circuit may be in a single device or chip, on a single motherboard, in a single chassis, in a plurality of enclosures at a single geographical location, in a plurality of enclosures distributed over a plurality of geographical locations, etc. Similarly, the term “module” may, for example, refer to physical electronic components (e.g., hardware) and any software and/or firmware (“code”) that may configure the hardware, be executed by the hardware, and or otherwise be associated with the hardware.

[0014] As utilized herein, circuitry or module is “operable” to perform a function whenever the circuitry or module comprises the necessary hardware and code (if any is necessary) to perform the function, regardless of whether performance of the function is disabled or not enabled (e.g., by a user-configurable setting, factory trim, etc.).

[0015] As utilized herein, “and/or” means any one or more of the items in the list joined by “and/or”. As an example, “x and/or y” means any element of the three-element set $\{(x), (y), (x, y)\}$. In other words, “x and/or y” means “one or both of x and y.” As another example, “x, y, and/or z” means any element of the seven-element set $\{(x), (y), (z), (x, y), (x, z), (y, z), (x, y, z)\}$. In other words, “x, y and/or z” means “one or more of x, y, and z.” As utilized herein, the term “exemplary” means serving as a non-limiting example, instance, or illustration. As utilized herein, the terms “for example” and “e.g.” set off lists of one or more non-limiting examples, instances, or illustrations.

[0016] As utilized herein, “train” refers to any vehicle, car or the like that operates on train racks. This may include vehicles, cars or the like that operating individually (e.g., as single vehicle) or within a group (e.g., one of cars in a multi-car railway train). Further, as utilized herein a train may include powered vehicles, cars or the like (e.g., incorporating power means for driving the car or the vehicle, autonomously and/or based on power provided to the car or the vehicle from external sources) and/or non-powered cars or vehicles.

[0017] The present disclosure is directed to control solutions for use in train systems. In particular, various implementations in accordance with the present disclosure are directed to providing virtual trip stops. In this regard, with virtual trip stops a train may, for example, be automatically stopped if the train violates a control signal without requiring track-mounted mechanical infrastructure. Transit systems may utilize, for example, Communication Based Train Control (CBTC) technology to bolster operational safety and improve throughput on busy train lines. While expensive to deploy, CBTC allows transit authorities to maximize the volume of passengers which may be transported without compromising safety and avoiding the great expense of adding additional track. The cost of adding additional track is significant, particularly in the United States, and especially so in heavily populated areas.

[0018] A “true CBTC system” depends exclusively upon the automated system to maintain safe train separation. CBTC systems provide contingency features to allow safe movement of trains in the event normal CBTC system operation fails. The throughput using the contingency system, however, is usually much lower than is achieved during normal CBTC operation. For busy transit systems that operate at or near full capacity during “rush hour” periods, the contingency system is too disruptive to normal passenger flow. As a result, many transit authorities choose to retain certain elements of legacy “fixed block signaling” train protection systems when they implement CBTC. They do this primarily to provide backup (supplemental) train protection systems in the event that the complex CBTC systems on the train, the wayside, or in the entire CBTC system malfunction. These supplemental systems are often referred to as “secondary train protection”.

[0019] Malfunctions and failures in CBTC operation are a particular issue during the “cutover” process when the CBTC system is first activated. An effective secondary train protection system is particularly important during cutover to avoid deterioration in the transit system throughput. Since the cutover process may extend for multiple months, even years, an effective secondary protection system can become particularly important.

[0020] However, not all aspects of fixed block signaling systems are retained, however, due to the significant expense associated with maintenance and repair of those signaling systems. Usually many of the track segments (blocks) are consolidated in single, large blocks to minimize the residual equipment upkeep cost. One portion of legacy fixed block signaling that is often left entirely intact with CBTC implementations are “home signals” and the associated “trip stops” (sometimes called a “train stop”, “tripcock”, or “tripper”).

[0021] A home signal is a wayside signal placed at the transition point of a route (such as at a track switch) or at the entrance to a block in order to regulate the movement of trains into that route or block. If a block is already occupied with a train, the home signal will display at stop indication to trains approaching the entrances to that block. This is intended to prevent train collisions, such as by enforcing train separation. The signal by itself, however, is unable to prevent train entry if the operator fails to respond to the stop signal. This fault condition is why trip stops are associated with home signals.

[0022] A trip stop (or train stop) is a train protection device that may trigger the emergency brake on a train, resulting in an automatic stop of a train if the train attempts to pass a restrictive (stop) signal which indicates the train must not proceed passed the signal. If the signal indicates a stop condition for the approaching track, the trip stop mechanically activates a brake-tripping arm upward. When a properly equipped train attempts to pass the trip stop in the activated condition, the raised arm on the trip stop contacts a hanging paddle on the train. That paddle is an activation valve for the emergency braking system on the train and causes the train to quickly stop, thus preventing entry into the zone protected by the home signal.

[0023] The combination of a home signal and the associated trip stop provide an automatic protection system as a backup in the event the CBTC system fails. This fallback protection prevents trains from moving through improperly aligned switches into areas where trains may collide. During

normal CBTC operation, the trip stop arm is commanded to move to the “down” position to allow the train to pass. In effect, a properly operating CBTC system overrides the home signal/trip stop combination.

[0024] Trip stops were first introduced over one hundred years ago. A trip stop is a relatively complex mechanical system with moving parts. Trip stops are expensive to install and to maintain. In addition, trip stops are track-mounted, which complicates track maintenance and repairs, increasing the cost and duration of disruption to track operation during service.

[0025] An additional disadvantage of the trip stop is that it must be positioned well in advance of the desired stopping point. This location in advance of the home signal is required to account for the maximum necessary emergency braking distance of the train to ensure the train will stop prior to entering the restricted area. If the train is traveling faster than the assumed maximum speed used for determining this distance, the trip stop will not prevent the train from entering the restricted area, possibly resulting in a collision. The CTA collision with the end-of-track bumping post at O’Hare airport on Mar. 24, 2014 is an example of how a trip stop may fail to safely stop a train it is traveling faster than the assumed maximum travel speed at that location.

[0026] Therefore, less costly and/or less complex alternatives to the trip stop may be desirable. In particular, for fallback protection in CBTC implementations, use of virtual trip stops may be a desirable option. In this regard, use of virtual trip stops reduces installation and maintenance costs, while also addressing weaknesses in conventional (legacy) solutions, as it improves system performance compared to conventional (legacy) trip stops as exemplified by the CTA accident noted above. This may be done, for example, by use of wireless communications. In this regard, in recent years, ultra-wideband (UWB) wireless precision ranging technology has been proposed and demonstrated at various transit agencies as a means of determining train position and/or train separation from other objects on a continuous basis. Several United States patents and patent applications describe various aspects and/or uses of this technology, including, e.g., U.S. Pat. Nos. 8,812,227; 9,043,131; 9,731,738; 10,778,363; and U.S. patent application Ser. Nos. 16/055,905; 16/290,576; 16/447,631; 16/118,941; and Ser. No. 16/521,269. Such UWB systems may be deployed to supplement CBTC implementations, providing improved train location technology, as well as providing a virtual trip stop capability.

[0027] Accordingly, in various implementations in accordance with the present disclosure, virtual trip stop may incorporate use of UWB technology to enhance operation. For example, virtual trip stop may incorporate UWB wireless ranging transducers mounted on each end face of the trains and at the approaches to each home signal location. The home signals may be retained, but the track-mounted physical trip stop mechanism may be eliminated, as the function typically performed by the physical trip stop may be performed “virtually”, such as by triggering the brakes in the train based on the wireless communications.

[0028] FIG. 1 illustrates an example virtual trip stop system, in accordance with the present disclosure. In this regard, FIG. 1 shows a block diagram of an example virtual trip stop system 10 which may be used to provide secondary protection by providing enforcement of restrictive home signal aspect indications.

[0029] The virtual trip stop system **10** is composed of two distinct elements. The track-side (wayside) portion comprises existing trackside home signal **20** which has been modified to support remote sensing of the signal aspects. The wayside portion also comprises vital (failsafe) signal aspect sensing circuitry and a vital processor **30**, which controls the UWB transceiver and antenna combination **40**. Each of these components may comprise suitable hardware (comprising, e.g., circuitry and/or other types of hardware), software, or any combination thereof configured for supporting virtual trip stop related operations or functions as described herein.

[0030] The UWB transceiver and antenna **40** may communicate wirelessly with train-borne UWB transceiver and antenna **50**, which in turn interfaced with the train-borne vital controller **60**. The virtual trip stop vital controller **60** may directly interface with the train emergency braking system **80**. In an alternative implementation, the emergency brake triggering by the virtual trip stop may be accomplished via the interface with the CBTC controller **70** on the train. Each of these components may comprise suitable hardware (comprising, e.g., circuitry and/or other types of hardware), software, or any combination thereof configured for supporting virtual trip stop related operations or functions as described herein.

[0031] A virtual trip stop installation at a home signal along the rail wayside may comprise the following components: UWB transceiver and antenna (with associated UWB processing), and a tower or structure to elevate the UWB antenna to an appropriate height for optimal performance, a redundant (fail-safe) home signal aspect sensing interface, a vital processor to create the appropriate status messages for UWB transmission, and a power converter to allow the system to be supplied by a convenient power source available at the home signal. The power source may be 115 VAC mains, or low-voltage DC signaling power, or one of other power variations found in transit systems.

[0032] The virtual trip stop controller on the train receives the home signal indication, which may be included with UWB range results, or from data-only UWB transactions. If the indication is not permissive (either restrictive or missing), the UWB-based vital controller will determine when it is appropriate to trigger the train emergency brakes in order to enforce the home signal.

[0033] The virtual trip stop controller performs UWB ranging operations to the home signal's associated UWB transducer and determines the distance to the home signal. This may consist of a calculation which includes the offset distance between the UWB transducer and the track transition point by which the train must stop, plus safety factors specified by the agency. The offset distance may be necessary when the UWB transceiver is installed on a structure which is separated from the home signal.

[0034] This UWB-ranging distance to the home signal is continuously updated (usually more than once per second), and this distance measurement is conveyed to the appropriate automatic train protection (ATP) controller on the train. The ATP function may be provided by a system on the train which is completely independent of the CBTC system (e.g., the train-borne vital controller **60** of FIG. 1), or it may be performed by a portion of the CBTC system installed on the train. Thus, when the CBTC system fails, there still may be an independent portion that remains operational due to redundancy, and that portion may retain functionality during

secondary train protection operation. Whichever processor performs the ATP function, it determines the maximum safe braking distance required for that location given the speed of the train and the train's operating condition.

[0035] The UWB range measurement system may also be used to detect the speed of the train, such as by calculating the "delta-separation" between the train UWB transducer and the home signal UWB transducer. Delta separation may be determined by making at least two separate measurements of the distance with a known time interval between the measurements. For example, if the first UWB distance measurement is 450.05 ft, the second measurement is 403.09 ft, and precisely one second elapsed between the distance measurements, it may be determined that the train is approaching the home signal at ~ 32.0 mph ($(450.05 \text{ ft} - 403.09 \text{ ft}) / (1 \text{ s}) = 46.96 \text{ ft/s}$ or ~ 32.0 mph).

[0036] If a permissive signal condition is not received from this particular home signal location (either a restrictive signal condition is received, or the signal state is missing from communications), the ATP processor will execute an emergency brake activation if the train operator fails to slow the train properly in advance of the home signal. The emergency brake will be triggered far enough in advance in order to assure that in worst case conditions, the emergency brake will be capable of stopping the train prior to passing the home signal. This is called the "safe braking distance."

[0037] Some transit agencies have significant safety margins such that even the virtual train stop will stop the train short of the home signal. If the operator desires to move forward to reach the home signal (to improve throughput), the virtual trip stop remains operational and will still enforce a train stop before the passes the home signal at the slower approach speed. However, the train may be stopped much closer to the home signal. This system behavior may be contrasted with legacy mechanical trip stop based solutions, where the train may have already passed the trip stop actuating arm on the first stop, so no further protection against violating the home signal may be provided.

[0038] In various implementations, the sensing of the home signal aspect indication may be performed in a non-intrusive fashion, such as by using inductive current sensing of the current flowing to the home signal indicating lamp(s) as described in more detail below.

[0039] FIG. 2 illustrates an example deployment of virtual trip stop system in a rail network, in accordance with the present disclosure. In this regard, FIG. 2 shows an overhead view of a rail vehicle on a rail line equipped with a virtual trip stop system. In particular, FIG. 2 illustrates a typical installation of both the physical trip stop and the virtual trip stop.

[0040] Train **100** was traveling left-to-right at a relatively low speed along track **110**. The home signal **120** was showing a restrictive signal aspect which caused the trip stop arm **140**, located in advance of the home signal, to be extended upward. The corresponding "sensing" arm on the passing train **100** contacted the trip stop arm and triggered the train emergency braking system. The train stopped a short time distance beyond the trip stop arm **140**.

[0041] Referring to FIG. 2, with the proposed virtual trip stop, the trip stop arm **140** and its associated motor and mechanism (hidden by the train) would be eliminated, replaced by the virtual trip stop UWB antenna and the associated electronics **130**. UWB range measurements and data communication are achieved between the virtual trip

stop and the train via UWB transceiver and antenna assemblies **150** which are installed at each end of the train **100**. In this regard, each of the UWB transceiver and antenna assemblies **150** may be similar to the train-borne UWB transceiver and antenna **50** of FIG. 1. The determination of which transceiver is used may be done in various ways. For example, in some implementations this may be done based on networking between the transceivers (e.g., UWB transceiver and antenna assemblies **150**) on each end of the train. The train-borne vital controller **60** may determine the direction of movement, such as based on “delta-separation” measurement and/or by utilizing other/available sources (e.g., the train’s wheel sensor inputs or other means), to determine which transceiver **150** is on the forward moving end of the train. The identified transceiver is used for virtual trip stop operation.

[0042] FIG. 3 illustrates an example home signal incorporating virtual trip stop related components, in accordance with the present disclosure. In this regard, FIG. 3 shows an example home signal **120** with associated conventional physical trip stop components as well as virtual trip stop components.

[0043] In particular, FIG. 3 illustrates a wayside installation of trip stop components, both of the legacy physical trip stop and the virtual trip stop. For the purposes of illustration, the physical trip stop is shown immediately adjacent to the home signal. In many installations, the home signal and the trip stop mechanism and trip arm are separated by considerable distance.

[0044] The home signal **120** is installed alongside the tracks **110**. The physical trip stop consists of two parts. The trip stop motor and actuating mechanism **160** is located between the tracks. A rotating shaft extends from the actuating mechanism **160** to the trip stop arm **140**. When the home signal indication is green (unrestrictive), the trip stop arm **140** is rotated downward so that the corresponding emergency brake tripping arm of passing trains will not contact the trip stop. When the home signal **120** is showing a red indication (restrictive), the trip stop actuating motor **160** rotates the trip stop arm **140** upward such that any passing train equipped with the emergency brake tripping arm will have the emergency brakes triggered.

[0045] Also shown in FIG. 3 for comparison purposes is the virtual trip stop components. Nonetheless, it should be noted that both the physical trip stop components **140** and **160**, and the virtual trip stop components **130** and **170** may not normally be in place simultaneously. An upward extension **170** from the home signal **120** provides mechanical support, power supply wiring, and home signal sensing conductors to the virtual trip stop UWB transceiver, antenna, and control electronics **130**. The upward extension **170** places the UWB antenna high (e.g., roughly 8 to 10 ft) above the track level. Positioning the antenna at such height may aid in ensuring proper and/or optimal operation of the UWB ranging system.

[0046] The virtual trip stop UWB ranging transducers allow precise measurement of the distance between the train and the home signal. When a home signal is in a permissive state (indicating that an approaching train may pass), the associated UWB transducer will transmit a permissive signal indication using a vital (fail-safe) protocol to approaching trains. When a home signal is in a restrictive state (indicating that an approaching train must stop), the associated UWB

transducer will transmit a restrictive indication using a vital (fail-safe) protocol to approaching trains.

[0047] Because UWB radios used in virtual trip stops may sense an approaching train many hundreds of feet away, the virtual trip stop (e.g., the associated UWB transducer) may be located near or on the home signal, unlike the legacy physical trip stop actuating motor and stop arm which must be located hundreds of feet prior to the home signal. By co-locating the virtual trip stop at the home signal, the installation cost of the system is reduced because signal communication cabling along the track to the remote trip stop location is not required. Costs are reduced even further because there is no track modification necessary to install the physical activation mechanism. Plus, with the elimination of the mechanism that must operate hundreds of times per day, the maintenance burden is also significantly lower.

[0048] Alternatively, the virtual trip stop may be placed wherever convenient and effective along the wayside at a location where a passing train may successfully make continuous range measurements to the UWB transducer at the distances necessary to allow the train emergency brake to stop the train prior to passing the home signal.

[0049] The distinct advantage of the UWB virtual trip stop over the legacy physical trip stop is that it provides an adaptive application point for the emergency brake prior to the home signal. The faster the train, the further back the emergency brake will be applied to ensure that the train stops prior to the home signal.

[0050] In contrast, to ensure safety, the physical trip stop must be placed at the maximum required emergency braking distance prior to the home signal. This distance must correspond to the maximum emergency brake stopping distance required at the highest achievable train speed. This lack of adaptability in the legacy physical trip stop system may have significant disadvantages as described in the following scenario.

[0051] For example, at 10 mph, the train’s emergency brake may stop the train in 40 ft or less; at 20 mph, the maximum stopping distance may be 120 ft; at 30 mph, the maximum stopping distance may be 250 ft; at 40 mph, the maximum stopping distance may be 430 ft; and at 50 mph, the maximum stopping distance may be 700 ft. If the maximum achievable speed of the train is 50 mph, to provide complete protection, the physical trip stop must be placed 700 ft in advance of the home signal in order to ensure that the train may be stopped prior to the track section protected by the home signal.

[0052] FIG. 4 illustrates example use scenarios comparing conventional trip stop and virtual trip stop in a rail network. In this regard, FIG. 4 shows an overhead view of two scenarios over the same section of track where a conventional trip stop has brought a train to a stop. In particular, the top view shows the result when a train was traveling at the maximum allowable track speed, whereas the bottom view shows the result when train was traveling at a much lower speed.

[0053] For example, the use scenario shown in the top drawing of FIG. 4 illustrates the result of a train stop caused by physical trip stop where the train was travelling at the maximum speed. The train **100** was traveling left to right on track **110**. The home signal **120** was indicating a restrictive aspect, which means the train must stop prior to passing the home signal **120**. In response to the restrictive signal, the trip stop motor **160** has raised the trip stop arm assembly **140**.

[0054] When the train **100** passed the trip stop arm **140**, the train emergency brake was triggered. As a result of the train's high speed, it required a significant distance to stop the train and the train ended up a small distance d_1 **180** short of the home signal **120**. The train stopped short of the home signal because the trip stop was located according to the worst case maximum emergency braking distance at the highest speed, while the train stopped in a shorter distance according to the nominal emergency braking distance at that speed.

[0055] In contrast, in the scenario where a train is approaching the same restrictive (red) home signal at 10 mph. The bottom drawing in FIG. 4 illustrates the result. The trip stop arm will extend any time the home signal aspect indication is restrictive and cause the passing train to apply emergency braking and stop at least 660 ft prior to the home signal. The trip stop is installed 700 ft in advance of the home signal, and the train stops in no more than 40 ft at 10 mph, so $700-40=660$ for the distance d_2 **190**, well short of the home signal **120**. This situation is inconvenient, counterproductive, possibly dangerous, and potentially unsafe.

[0056] This situation is inconvenient, because the train has been stopped far in advance of the home signal instead of properly just before the home signal, as well as inefficient, as stopping and starting the train wastes energy. If the train in the next block, which caused the restrictive home signal, moves out of the block protected by the home signal within the next 40 seconds, stopping the train was unnecessary. The approaching train could have continued moving at 10 mph towards the home signal and the home signal would have changed to a permissive indication prior to the train reaching the home signal stopping point.

[0057] This situation is counterproductive because the train will now take considerably more time to enter the block protected by the home signal once the signal becomes permissive. This will slow down throughput in the system. In addition, since the train stopped well before the home signal, the rear of the train may block entrance of a following train into a station, or into another protected block, cascading additional delays further back through the system. This is particularly problematic during "rush hour" when transit capacity is often strained even without additional delays associated with premature braking due to trip stops.

[0058] This situation is possibly dangerous because an unnecessary emergency braking event has been triggered. The train still had plenty of distance to stop before the home signal, so the emergency brake application may not have been necessary. Emergency braking may result in passenger injuries due to the aggressive braking rate employed.

[0059] This situation which resulted in stopping the train in advance of the home signal may also degrade safety. When the train is stopped so far back from the home signal, the train operator may feel pressured to advance the train to the home signal. This may be the result of the knowledge that the prematurely stopped train is impacting rush hour throughput. The operator may hastily reset the emergency brake and advance. Now, however, there is no longer a trip stop between the train and the home signal to enforce a train stop prior to entering the next block of track. If the train is short, and/or the train was moving at a sufficient speed when stopped by the trip stop, such that there are no remaining brake actuators on the train which will contact the trip stop arm, there is no remaining mechanism to automatically prevent the train from entering the unauthorized block of

track beyond the home signal. If the operator is inattentive or is distracted again, and fails to appropriately stop the train prior to the home signal, the train may enter an unauthorized block of track.

[0060] The classic solution to address the issue of the fixed brake application point of the trip stop and the associated issues described above is to add more trip stops, and/or add advance (approach) home signals with associated trip stops, and/or timed trip stops that will actuate train brakes only if the train is traveling above a defined speed. Each of these measures add significantly more installation and maintenance costs, further exacerbating the issue of the cost of trip stops in an already costly CBTC environment. The virtual trip stop may also be used to provide or support other functionalities, such as enforcing speed limits—e.g., on the approach to a home signal, to ensure that the maximum stopping distance is within the capability of the virtual trip stop system.

[0061] Because of the infinitely adjustable trigger point feature of the virtual trip stop, the complications described above with physical trip stops are eliminated. The virtual trip stop system automatically compensates for train speed when determining the point where emergency brake application is required. With a virtual trip stop, both of the aforementioned operating scenarios (a high speed and low speed approach to a restrictive home signal) would result in the train stopping as shown in the scenario shown in the top drawing of FIG. 4, where the train stops a small distance d_1 **180** short of the home signal **120**. Only with the legacy physical trip stop installation would the bottom drawing scenario occur, with the train stopping at distance d_2 **190**, well short of the home signal **120**. Note also that in a virtual trip stop installation, trip stop arm **140** and actuating mechanism **160** would be eliminated.

[0062] A virtual trip stop installation onto a train may comprise the following components: UWB transceiver and antenna (with associated UWB processing), a vital processor to determine if the emergency brake should be initiated in response to UWB data, an interface to the train emergency brake system, an interface to the CBTC vehicle on-board controller (VOBC), and a connection to low-voltage power from the train. Some installations may also comprise a user display or an interface to an existing display in the cab of the train to convey status and health indications to the operator. The status and indication functions may be handled by the CBTC system.

[0063] FIG. 5 illustrates an example implementation of a home signal with fail-safe sensing, in accordance with the present disclosure. In this regard, shown in FIG. 5 is an electrical schematic of an example home signal aspect fail-safe sensing configuration in accordance with at least one embodiment of the present technology. In particular, FIG. 5 illustrates one such implementation of home signal aspect sensing. Such a current sensor **520** may consist of multiple turns of magnet wire wrapped on an appropriate toroidal magnetic core (such as a ferrite core) in the case of AC-powered home signals.

[0064] In the event the home signal is DC-powered, the current sensor may consist of a Hall effect sensor placed in the gap of a cut toroidal tape-wound high permeability core (such as a nickel-iron core). Such a non-contacting current sensing system allows the sensing electronics to be com-

pletely isolated from the home signal circuit. Safety standards may require as much as 3,000 VAC of galvanic isolation.

[0065] For fail-safe detection of the home signal aspect, dual current sensors may be employed on each conductor, as shown in FIG. 5, where there are two independent current sensors 520 on each signal aspect conductor. The conductor 530 for signal lamp 510 passes through two current sensors 520, providing redundant sensing.

[0066] This current sensor redundancy allows for one sensor to fail while the other sensor will still detect the signal state. Additional safety in sensing may be achieved by sensing each home signal aspect conductor, such that a restrictive state is determined any time anything other than a single permissive aspect is lit. Fault conditions such as no aspect and improper multiple aspects may be treated as a restrictive indication for safety reasons.

[0067] Fault handling of the signal aspect sensing shown in FIG. 5 is handled in the UWB transceiver, antenna, and control electronics 130. Each current sensor is connected to the vital current sensor and processor 40, which senses if current is flowing in the corresponding signal lamp, indicating that the lamp is lit. Each independent current sensor input is processed in a fail-safe fashion by the vital processor 40, and the results of the determination is sent to the remote train requesting range measurements and status updates via the UWB transceiver 30.

[0068] Precision UWB range measurements are used by the virtual trip stop train-borne controller to determine the range and closing speed to the home signal, and those range measurements may also include data which identifies the signal aspect displayed by the associated home signal. There is another function of the UWB range measurements which is often required to allow determination of which home signal controls the movement of the host train.

[0069] When there is more than one operating track, the train-borne controller must determine the track upon which the train is traveling. This is necessary to select the appropriate home signal, and not the home signal which controls train flow on the opposite track or other tracks adjacent to the one upon which the train is operating.

[0070] In order to make this operating track determination, it may be necessary to locate more than one UWB transceiver with the virtual trip stop for each home signal. Multiple UWB transceivers at known locations (stored in a non-volatile memory track map in the train-borne virtual trip stop controller) allow the processor to determine the operating track using geometric analysis of range results. The additional UWB transceivers may be located prior to the home signal in order to allow and/or confirm operating track determination well in advance of the associated home signal.

[0071] The additional UWB transceivers for operating track determination also allow detection of failures of individual UWB transceivers. For example, if one or two UWB transceivers located prior to the home signal are responsive, but the expected home signal UWB transceiver is not responsive, a fault may be flagged and logged for service. This condition may also cause the virtual trip stop to enter a fail-safe condition of assuming a restrictive signal indication on the home signal. The virtual trip stop controller may make this association of UWB transceivers via the on-board track map stored in the controller. The track determination technique and track map technology is described in U.S. Pat. No. 10,778,363. Virtual trip stop operational integrity may

also be assured during normal CBTC operation by having the CBTC VOBC confirm that it is receiving proper status messages from the virtual trip stop train-borne processor. The CBTC system may know the location, and the distance to an upcoming home signal. The VOBC can verify that the virtual trip stop system is detecting the home signal status and distance to home signal when the train reaches a threshold where the UWB radios should be capable of ranging and data communications.

[0072] FIG. 6 illustrates a flowchart of an example process for enforcing rail vehicle adherence to a home signal using a virtual trip stop, in accordance with the present disclosure. In this regard, shown in FIG. 6 is a flow diagram 600 of an example process for enforcing rail vehicle adherence to a home signal using a virtual trip stop.

[0073] In particular, the flow diagram 600 depicts a method for implementing virtual trip stop to enforce home signal restrictions. The method may be performable using the structures and functions described herein. The steps illustrated in the flow diagram 600 may be performable at least in part by one or more processors, such as the processor (s) depicted in FIG. 1, which comprise the trackside vital processor 30, the train-borne vital processor 60, and the CBTC vehicle-on-board controller 70.

[0074] At the start of the process, upon power up of the virtual trip stop controller located on a train, the proximity to any wayside virtual trip stop systems is not known, and as such the controller reverts to a "location unknown" condition. Hence, at step 605 the train-borne controller transmits an UWB "all units respond" request. At step 610, all properly equipped and configured virtual trip stop UWB radios located close enough to successfully receive the transmission respond via UWB with their unique ID.

[0075] At step 615, the train-borne controller inspects the messages and rapidly determines the approximate range to each responding UWB radio using the data from each transmitted response. The train-borne controller then executes, at step 620, precision range measurements to several of the closest responding radios, and then, at step 625, repeats the range measurements after a precise time delay. The resulting data may allow the train-borne controller to determine, at step 630, the direction of movement, the speed of the train to each UWB responder, and the operating track. The train-borne controller then selects, at step 635, the next virtual trip stop ahead (e.g., nearest virtual trip stop for the operating track), the signal indication of the associated home signal, and the closing velocity to the next virtual trip stop. If there was not a sufficient quantity of UWB responders to determine all of these values, partial data may still be helpful, and the train-borne controller will continue to attempt range measurements to the appropriate targets and may add additional targets based upon data in the stored track map.

[0076] At step 640, the computed distance to the next home signal may be adjusted by a programmed offset value if the home signal and the associated UWB transceiver are not co-located. The offset value may be obtained from the programmed track map, or may be included in the data sent by the home signal UWB transceiver.

[0077] At step 645, once the speed of the train is determined, the safe braking distance may be computed by the train-borne controller. At step 650, train train-borne controller periodically updates range and home signal indication with nearest virtual trip stop. At step 655, a comparison of

the current distance to the home signal and the safe braking distance coupled with the home signal aspect indication will determine when and if it is necessary to enforce a stop by triggering the emergency brake. For example, if the home signal indication is restrictive, or if signal state is not confirmed, and safe braking distance is violated, the train emergency brake is commanded.

[0078] At step **660**, once the home signal/virtual trip stop is passed, the train-borne controller may consult the stored track map to determine the next home signal and may begin ranging attempts with the next home signal. At step **665**, if there is no response from the next home signal, the train-borne controller may return the location state to “unknown”, and begin the acquisition process just described back into operation.

[0079] Furthermore, in some implementations the steps illustrated in the flow diagram **600** may be performed in a different order, or some steps may be omitted, such as according to design and/or preferences. The steps illustrated in the flow diagram **600**, or a portion thereof, may be performable by software, hardware, and/or firmware. The steps illustrated in the flow diagram **600**, or portion thereof, may also be expressible through a set of instruction stored on one or more computer-readable storage devices, such as RAM, ROM, EEPROM, flash memory, other non-volatile electronic memory, optical disk, magnetic disk, solid state drive, magnetic tape, and/or the like.

[0080] An example system for train control, in accordance with the present disclosure, comprises a train-based control unit configured for deployment on a train operating within a rail network, with the train-based control unit comprising one or more transceivers configured for transmitting and/or receiving wireless signals, and one or more circuits configured to: process signals and data, and perform based, at least in part, on the processing of signals one or more functions relating to operations of the train-based control unit. The rail network comprises one or more wayside control units configured for deployment on or near tracks in the rail network, with each wayside control unit coupled or attached to a train signal (e.g., home signal), and the train-based control unit configured to communicate with any wayside control unit that comes within communication range of the train-based control unit, to determine based on processing of communicated signals with at least one wayside control unit one or both of operation information and state information, and to generate based on the operation information and the state information, control information configured for use in controlling one or more functions of the train in conjunction with operation in the rail network. The operation information relate to one or both of the at least one wayside control unit and the train. The state information relate to a state of train signal.

[0081] In an example implementation, the operation information comprises ranging information, and wherein the train-based control unit is configured to determine range to at least one wayside control unit.

[0082] In an example implementation, the train-based control unit is configured to determine approximate range to each wayside control unit within communication range of the train-based control unit.

[0083] In an example implementation, the train-based control unit is configured to: identify at least one nearest wayside control unit, and obtain, based on processing of

received signals, precision range measurements to the at least one nearest wayside control unit.

[0084] In an example implementation, the train-based control unit is configured to repeat obtaining range measurements after a time delay.

[0085] The system of claim **1**, wherein the operation information comprises one or more of direction, speed, and location, wherein the train-based control unit is configured to determine at least one of direction of movement of the train, speed of the train, location of the train, and operating track based, at least in part, on processing of received signals from at least one wayside control unit.

[0086] In an example implementation, the train-based control unit is configured to determine at least one of the direction of movement of the train, the speed of the train, the location of the train, and the operating track based on range measurement to at least one wayside control unit.

[0087] In an example implementation, the train-based control unit is configured to select a nearest virtual trip stop based on identifying of a train signal (e.g., home signal), wherein the train signal is determined based on a corresponding wayside control unit.

[0088] In an example implementation, the train-based control unit is configured to determine a safe braking distance for the virtual trip stop based on speed of the train.

[0089] In an example implementation, the state information comprises an indication of whether the state of train signal is restrictive, permissive, or not confirmed, and wherein the train-based control unit is configured to: select a virtual trip stop based on identifying a particular wayside control unit, and generate or adjust the control information based on the indication.

[0090] In an example implementation, the one or more functions of the train comprise braking, and wherein the train-based control unit is configured to generate a safe braking command based on a determination that the state of train signal is restrictive or is not confirmed.

[0091] In an example implementation, the train-based control unit is configured to communicate with at least one wayside control unit that comes within communication range of the train-based control unit using ultra-wideband (UWB) signals.

[0092] An example system for train control, in accordance with the present disclosure, comprises a wayside control unit configured for deployment on or near tracks in a rail network, with the wayside control unit comprising one or more transceivers configured for transmitting and/or receiving wireless signals, and one or more circuits configured to process signals and data, and perform based, at least in part, on the processing of signals one or more functions relating to operations of the wayside control unit. The wayside control unit is coupled or attached to the train signal, and the wayside control unit is configured to communicate with any train-based control unit that comes within communication range of the wayside control unit.

[0093] In an example implementation, the wayside control unit is configured to communicate with at least one train-based control unit that comes within communication range of the wayside control unit using ultra-wideband (UWB) signals.

[0094] Aspects of the techniques described herein may be implemented in digital electronic circuitry, computer software, firmware, or hardware, including the structures disclosed herein and their structural equivalents, or in various

combinations. Aspects of the techniques described herein may be implemented using a non-transitory computer readable medium and/or storage medium, and/or a non-transitory machine readable medium and/or storage medium, having stored thereon, a machine code and/or a computer program having at least one code section executable by a machine and/or a computer, thereby causing the machine and/or computer to perform the processes as described herein.

[0095] Each of the computer programs may have, for example, one or more sets of program instructions residing on or encoded in the non-transitory computer-readable storage medium for execution by, or to control the operation of, one or more processors of the machine or the computer. Alternatively or in addition, the instructions may be encoded on an artificially-generated propagated signal, for example, a machine-generated electrical, optical, or electromagnetic signal that may be generated to encode information for transmission to a suitable receiver apparatus for execution by one or more processors.

[0096] A non-transitory computer-readable medium may be, or be included in, a non-transitory computer-readable storage device, a non-transitory computer-readable storage substrate, a random or serial access memory array or device, various combinations thereof. Moreover, while a non-transitory computer-readable medium may or may not be a propagated signal, a non-transitory computer-readable medium may be a source or destination of program instructions encoded in an artificially-generated propagated signal. The non-transitory computer-readable medium may also be, or be included in, one or more separate physical components or media (for example, CDs, disks, or other storage devices).

[0097] Certain techniques described in this specification may be implemented as operations performed by one or more processors on data stored on one or more computer-readable mediums or received from other sources. The term “processor” may encompass various kinds of apparatuses, devices, or machines for processing data, including by way of example a central processing unit, a microprocessor, a microcontroller, a digital-signal processor, programmable processor, a computer, a system on a chip, or various combinations thereof. The processor may include special purpose logic circuitry, for example, a field programmable gate array or an application-specific integrated circuit.

[0098] Program instructions (for example, a program, software, software application, script, or code) may be written in various programming languages, including compiled or interpreted languages, declarative or procedural languages, and may be deployed in various forms, for example as a stand-alone program or as a module, component, subroutine, object, or other unit suitable for use in a computing environment. Program instructions may correspond to a file in a file system. Program instructions may be stored in a portion of a file that holds other programs or data (for example, one or more scripts stored in a markup language document), in a dedicated file or in multiple coordinated files (for example, files that store one or more modules, sub-programs, or portions of code). Program instructions may be deployed to be executed on one or more processors located at one site or distributed across multiple sites connected by a network.

[0099] The present technology has now been described in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains, to practice the same. It is to be understood that the foregoing describes

preferred embodiments and examples of the present technology and that modifications may be made therein without departing from the spirit or scope of the invention as set forth in the claims. Moreover, it is also understood that the embodiments shown in the drawings, if any, and as described above are merely for illustrative purposes and not intended to limit the scope of the invention. As used in this description, the singular forms “a,” “an,” and “the” include plural reference such as “more than one” unless the context clearly dictates otherwise. Where the term “comprising” appears, it is contemplated that the terms “consisting essentially of” or “consisting of” could be used in its place to describe certain embodiments of the present technology. Further, all references cited herein are incorporated in their entireties.

[0100] Accordingly, various embodiments in accordance with the present invention may be realized in hardware, software, or a combination of hardware and software. The present invention may be realized in a centralized fashion in at least one computing system, or in a distributed fashion where different elements are spread across several interconnected computing systems. Any kind of computing system or other apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a general-purpose computing system with a program or other code that, when being loaded and executed, controls the computing system such that it carries out the methods described herein. Another typical implementation may comprise an application specific integrated circuit or chip.

[0101] Various embodiments in accordance with the present invention may also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which when loaded in a computer system is able to carry out these methods. Computer program in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following: a) conversion to another language, code or notation; b) reproduction in a different material form.

[0102] While the present invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the present invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present invention without departing from its scope. Therefore, it is intended that the present invention not be limited to the particular embodiment disclosed, but that the present invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A system for train control, comprising:

a train-based control unit configured for deployment on a train operating within a rail network, the train-based control unit comprising:

one or more transceivers configured for transmitting and/or receiving wireless signals; and

one or more circuits configured to:
 process signals and data, and
 perform based, at least in part, on the processing of
 signals one or more functions relating to opera-
 tions of the train-based control unit;

wherein:

the rail network comprises one or more wayside control
 units configured for deployment on or near tracks in
 the rail network;
 each wayside control unit is coupled or attached to a
 train signal; and
 the train-based control unit is configured to:
 communicate with any wayside control unit that
 comes within communication range of the train-
 based control unit;
 determine based on processing of communicated
 signals with at least one wayside control unit:
 operation information relating to one or both of
 the at least one wayside control unit and the
 train; and
 state information relating to a state of train signal;
 and
 generate based on the operation information and the
 state information, control information configured
 for use in controlling one or more functions of the
 train in conjunction with operation in the rail
 network.

2. The system of claim 1, wherein the operation informa-
 tion comprises ranging information, and wherein the train-
 based control unit is configured to determine range to at least
 one wayside control unit.

3. The system of claim 2, wherein the train-based control
 unit is configured to determine approximate range to each
 wayside control unit within communication range of the
 train-based control unit.

4. The system of claim 2, wherein the train-based control
 unit is configured to:

identify at least one nearest wayside control unit; and
 obtain, based on processing of received signals, precision
 range measurements to the at least one nearest wayside
 control unit.

5. The system of claim 2, wherein the train-based control
 unit is configured to repeat obtaining range measurements
 after a time delay.

6. The system of claim 1, wherein the operation informa-
 tion comprises one or more of direction, speed, and location,
 wherein the train-based control unit is configured to deter-
 mine at least one of direction of movement of the train,
 speed of the train, location of the train, and operating track
 based, at least in part, on processing of received signals from
 at least one wayside control unit.

7. The system of claim 6, wherein the train-based control
 unit is configured to determine at least one of the direction
 of movement of the train, the speed of the train, the location

of the train, and the operating track based on range mea-
 surement to at least one wayside control unit.

8. The system of claim 1, wherein the train-based control
 unit is configured to select a nearest virtual trip stop based
 on identifying of a train signal, wherein the train signal is
 determined based on a corresponding wayside control unit.

9. The system of claim 8, wherein the train-based control
 unit is configured to determine a safe braking distance for
 the virtual trip stop based on speed of the train.

10. The system of claim 1, wherein the state information
 comprises an indication of whether the state of train signal
 is restrictive, permissive, or not confirmed, and wherein the
 train-based control unit is configured to:

select a virtual trip stop based on identifying a particular
 wayside control unit; and
 generate or adjust the control information based on the
 indication.

11. The system of claim 10, wherein the one or more
 functions of the train comprise braking, and wherein the
 train-based control unit is configured to generate a safe
 braking command based on a determination that the state of
 train signal is restrictive or is not confirmed.

12. The system of claim 1, wherein the train-based control
 unit is configured to communicate with at least one wayside
 control unit that comes within communication range of the
 train-based control unit using ultra-wideband (UWB) sig-
 nals.

13. A system for train control, comprising:

a wayside control unit configured for deployment on or
 near tracks in a rail network, the wayside control unit
 comprising:

one or more transceivers configured for transmitting
 and/or receiving wireless signals; and

one or more circuits configured to:

process signals and data, and

perform based, at least in part, on the processing of
 signals one or more functions relating to opera-
 tions of the wayside control unit;

wherein:

the wayside control unit is coupled or attached to the
 train signal; and

the wayside control unit is configured to:

communicate with any train-based control unit that
 comes within communication range of the way-
 side control unit.

14. The system of claim 13, wherein the wayside control
 unit is configured to communicate with at least one train-
 based control unit that comes within communication range
 of the wayside control unit using ultra-wideband (UWB)
 signals.

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