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(54) **DETERMINING AN ACTIVITY OF A MOBILE MACHINE**

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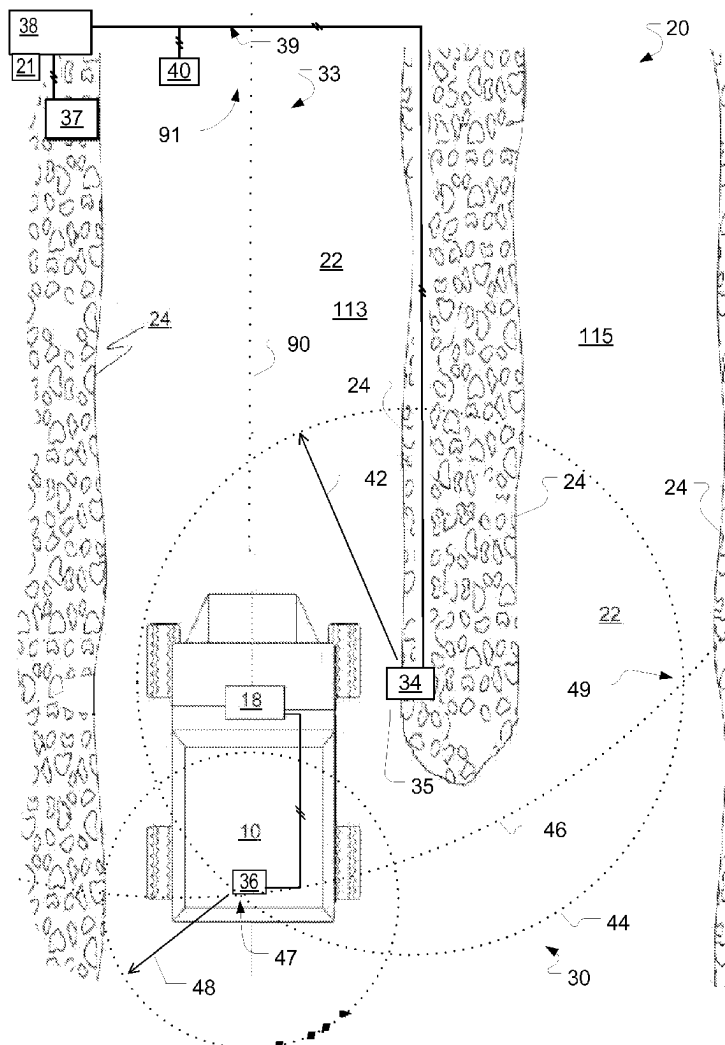
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(57) **ABSTRACT**

Disclosed herein is a method for determining an activity associated with a mobile machine in an underground mine, and a system (30) configured to perform the method. The method comprises communicating by a radio-frequency communication between a first ranging device (34) at a known location (35) within the mine and a second ranging device (36) located on the mobile machine (10). The method further comprises determining a position of the mobile machine (10) based at least on a time-based characteristic associated with the radio-frequency communication. The method further comprises identifying an activity of the mobile machine (10) based on the determined position in the mine (20).



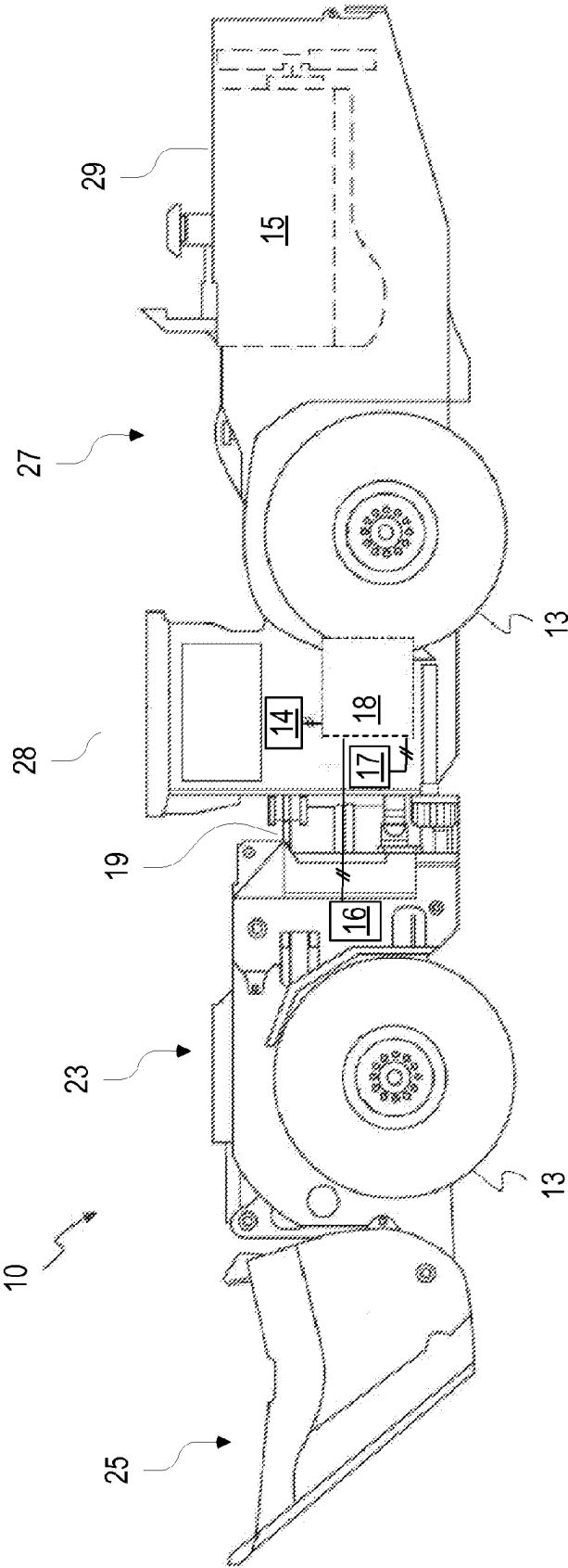
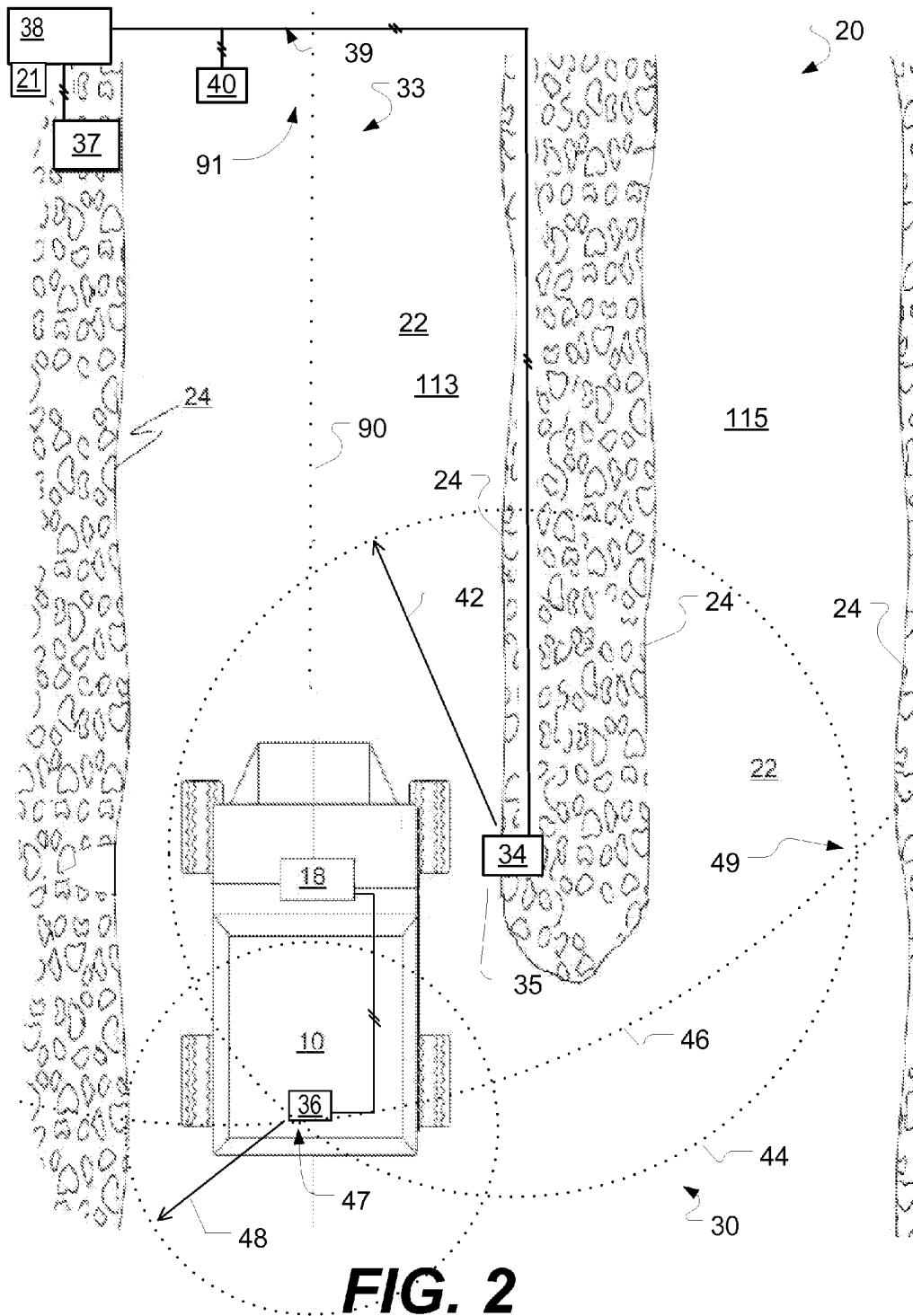


FIG. 1



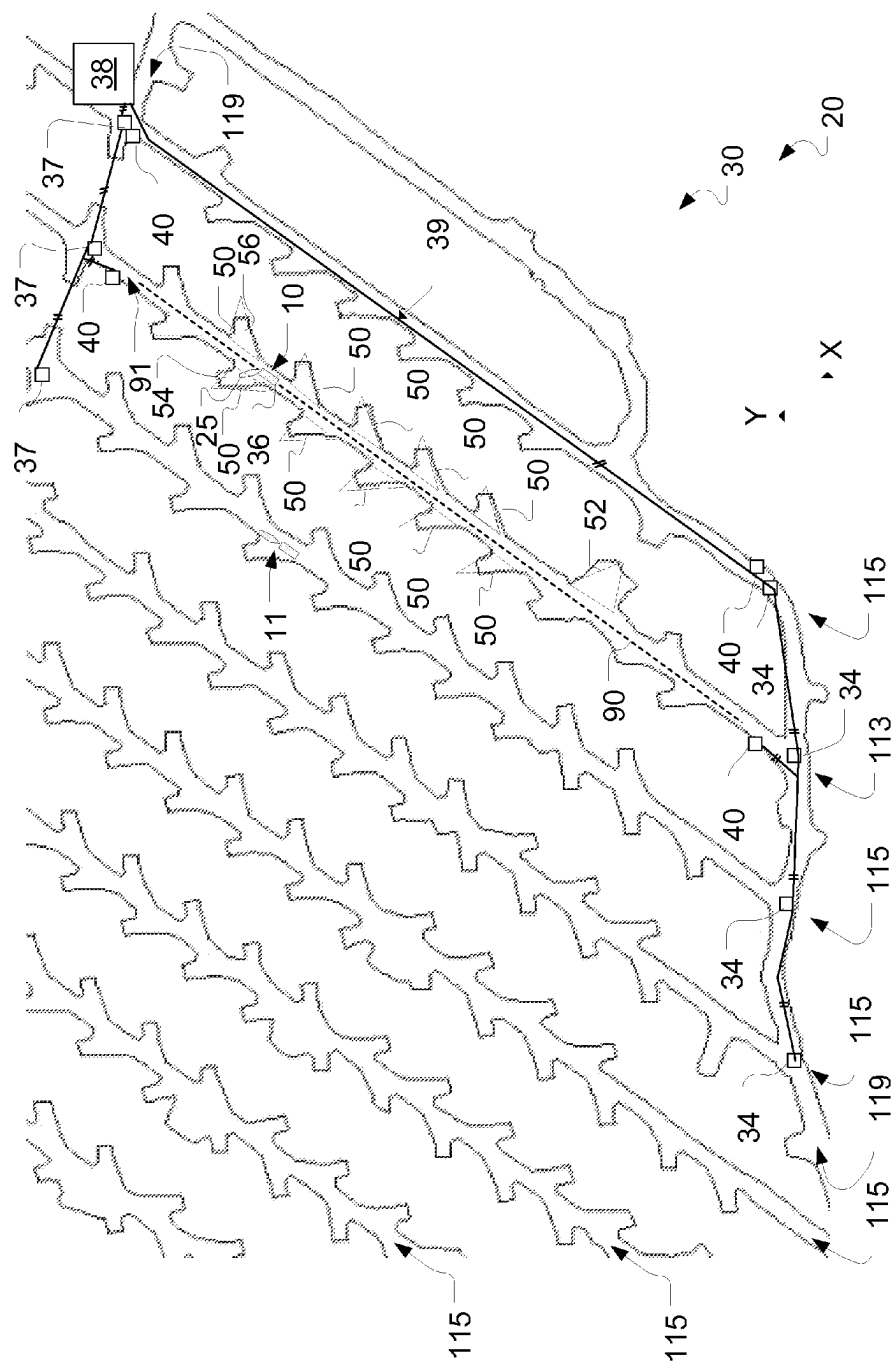
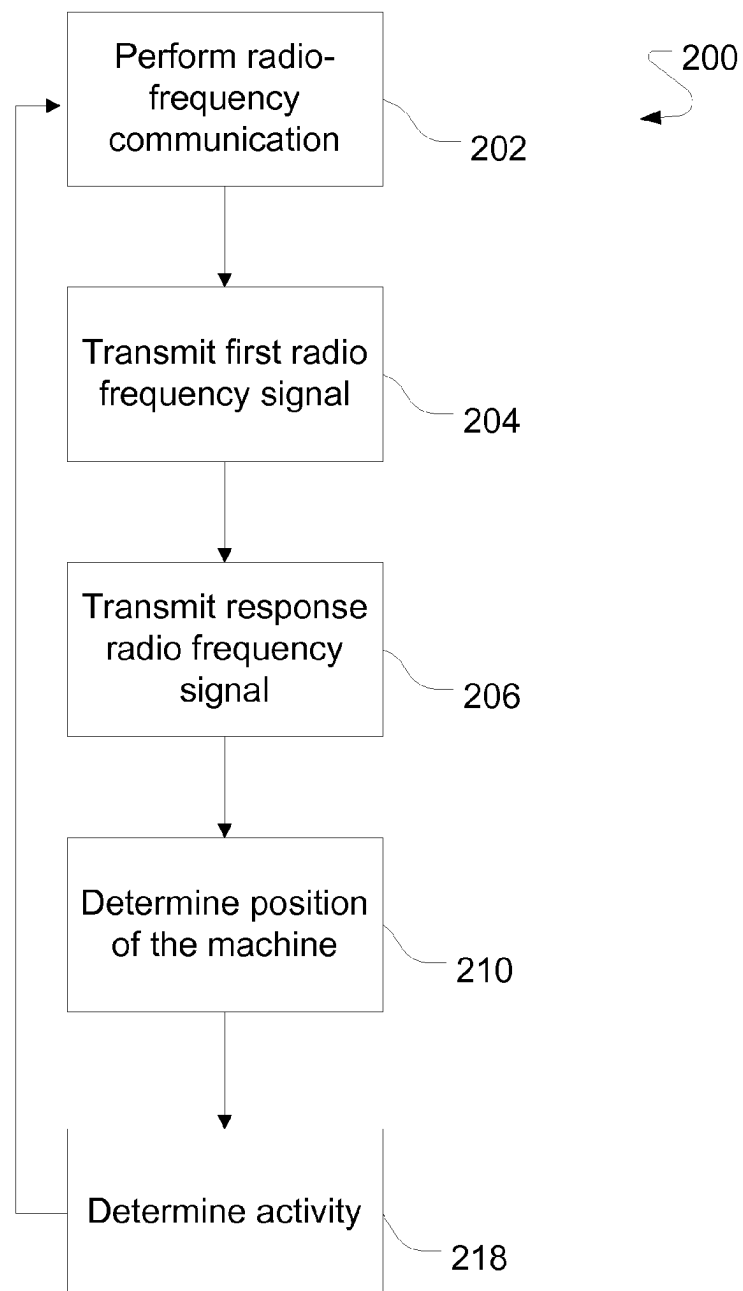
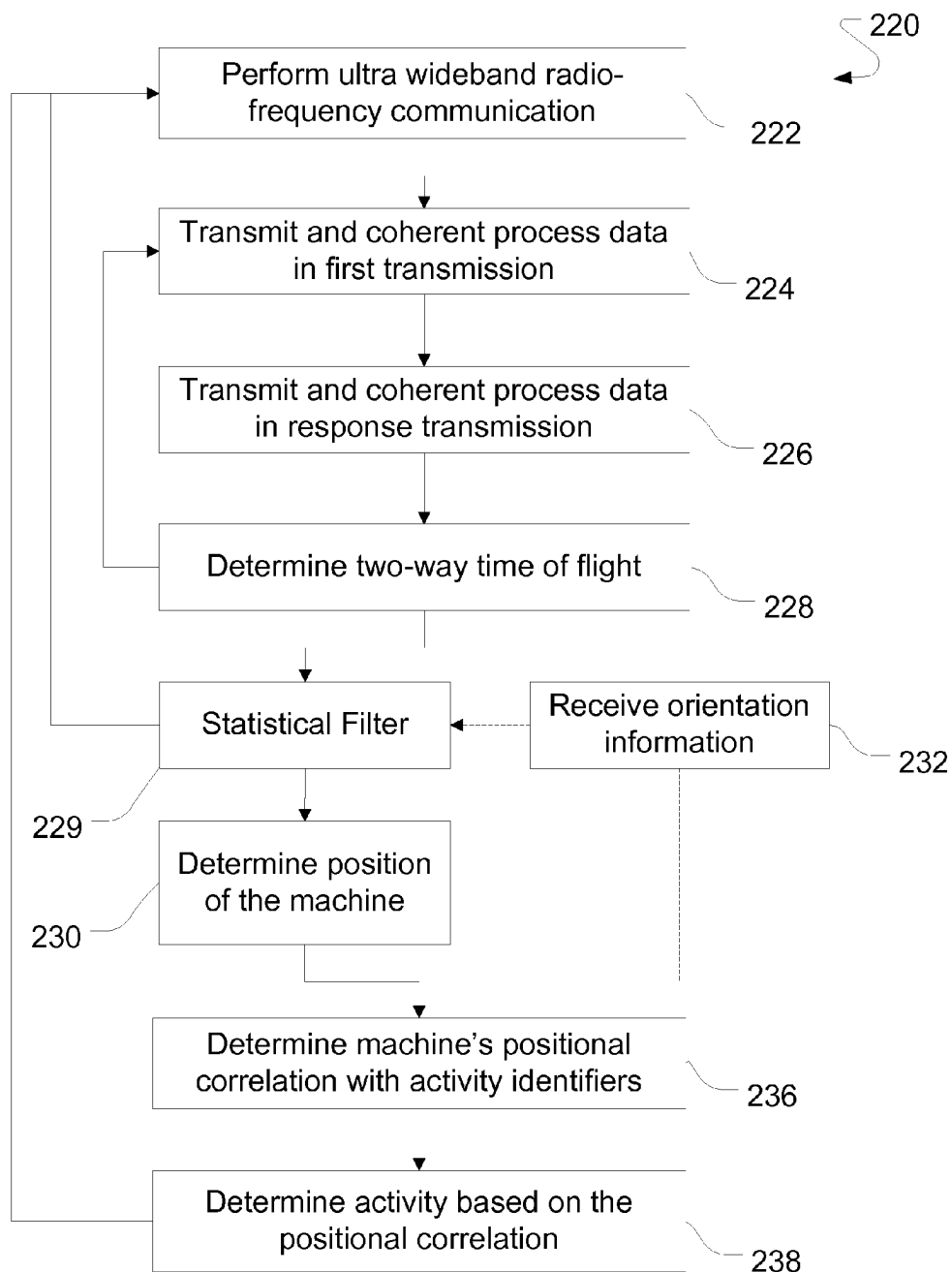


**FIG. 3**

**FIG. 4**

**FIG. 5**

## DETERMINING AN ACTIVITY OF A MOBILE MACHINE

### TECHNICAL FIELD

**[0001]** The present disclosure relates generally to a method and system for determining an activity of a mobile machine. The method and system are especially relevant to determining an activity in an underground mine

### BACKGROUND

**[0002]** Machines such as, for example, haul trucks, drills, loaders, conveyors, and other types of heavy equipment are commonly used in underground mining applications to perform a variety of tasks. Unlike above-ground mining applications, underground mining sites do not have access to GPS (Global Positioning System) signals, yet knowledge of a machine's on-site location is desirable, for example, with respect to the site geography.

**[0003]** In some underground mining applications, it is desirable to monitor the specific tasks required of the machine or machine(s) in the underground mine. For example, in some cases where at least one machine is assigned to move ore in a mine, it is sometimes desirable to remotely monitor the movement of ore. This may be achieved by identifying when and where a machine loads ore and the location from which it is loaded, and identifying when and where the machine then dumps the loaded ore. Some systems use RFID tags and readers to identify the machine's activity. For example, the machine may have an RFID reader mounted to it, while RFID tags are mounted at each of one or more drawpoints (at which ore may be loaded) and each of one or more ore passes (at which ore may be dumped). The drawpoints and ore passes and their corresponding RFID tags are stored in a computer readable memory. When the machine arrives at a drawpoint or ore pass, the RFID reader comes into proximity with the RFID tag at the drawpoint or ore pass, allowing the RFID reader to identify the RFID tag. Depending on whether the RFID tag corresponds to a drawpoint or an ore pass, the system can thus attribute the activity of loading ore from the drawpoint or dumping ore at the ore pass. The specific drawpoint or ore pass associated with the activity may be identified by knowing which drawpoint or ore pass the identified RFID tag is associated with. However, the RFID tags need to be stored inside the drawpoint or inside the ore pass to be sure to identify that the machine has in fact entered the drawpoint or ore pass. This requires careful distribution and positioning of the RFID tags within the mine. Furthermore, the RFID tags can easily become damaged, requiring replacement. This adds to the costs and reduces the reliability of the system.

**[0004]** In some underground mining applications using a load-haul-dump (LHD) loader, loading or dumping activities may be determined by identifying when a bucket for carrying ore on the LHD loader (or a portion of the bucket) is situated in a position within the mine that corresponds to drawpoint or orepass, respectively. The position of the bucket is determined from information from an articulation sensor and from a tracked position of a Lidar sensor on the machine. However, Lidar positioning systems tend to be expensive and, in harsh and dirty underground mine environments, often have reliability and maintenance issues. Additionally, some mining applications may not be suitable for operating Lidar positioning systems, or the use of such systems may be difficult to implement.

**[0005]** The disclosed method and system are directed to overcoming or at least ameliorating one or more of the problems set forth above.

### SUMMARY

**[0006]** In one aspect, there is disclosed a method for determining an activity associated with a mobile machine in an underground mine. The method comprises communicating by a radio-frequency communication between a first ranging device at a known location within the mine and a second ranging device located on the mobile machine. The method further comprises determining a position of the mobile machine based at least on a time-based characteristic associated with the radio-frequency communication. The method further comprises identifying an activity of the mobile machine based on the determined position in the mine.

**[0007]** In another aspect, there is disclosed a system for determining an activity associated with a mobile machine in an underground mine. The system comprises a first ranging device for positioning at a known location in the mine and a second ranging device for attaching to the mobile machine. The first and second ranging devices are configured to perform a radio-frequency communication therebetween. The system further comprises a memory system for storing data defining a geographic frame of reference. The system further comprises a processing system configured to determine a position of the mobile machine based at least on a time-based characteristic associated with the radio-frequency communication. The processing system is further configured to identify an activity of the mobile machine based on the determined position in the mine. This is achieved by determining a positional correlation between the determined position of the mobile machine and an activity identifier from a plurality of activity identifiers associated with respective positions in the mine. The positional correlation is determined with respect to the stored data defining a geographic frame of reference.

**[0008]** As used herein, the term "comprises" (and grammatical variants thereof) is used inclusively and does not exclude the existence of additional features, elements or steps.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0009]** Various aspects and features of an embodiment of the invention will be described with reference to the following figures which are provided for the purposes of illustration and by way of non-limiting example only.

**[0010]** FIG. 1 is a pictorial illustration of an exemplary disclosed machine;

**[0011]** FIG. 2 is a pictorial illustration of an exemplary system that may be used to determine an activity of the mobile machine of FIG. 1, the machine being illustrated in a simplified manner;

**[0012]** FIG. 3 is a pictorial illustration of a worksite in which the system of FIG. 2 may operate;

**[0013]** FIG. 4 is a flowchart depicting an exemplary disclosed method; and

**[0014]** FIG. 5 is a flowchart depicting an embodiment of the exemplary disclosed method.

### DETAILED DESCRIPTION

**[0015]** FIG. 1 illustrates a machine 10 having an exemplary disclosed system. Machine 10 embodies a mobile machine configured to perform one or more operations associated with

an industry such as mining, construction, farming, transportation, or any other industry known in the art. For example, machine 10 may be a load-moving machine such as a haul truck, a loader, an excavator, a wheel tractor, a scraper, or any other like machine. Machine 10 may be used above-ground or underground, but in the present disclosure the machine 10 is used underground. For example, FIG. 1 more specifically illustrates an underground mining load-haul-dump (LHD) loader, which may be used to access a load site in a mine (eg from a drawpoint), haul a load away from the load site, and release the load at a dump site (eg at an ore pass). Machine 10 may be manually controlled, semi-autonomously controlled, or fully-autonomously controlled. Machine 10 includes one or more traction devices that propel machine 10. In the exemplified embodiment, machine 10 has four traction devices in the form of respective wheels 13. The machine 10 also includes, among other things, movement sensors 14 that sense various movements of machine 10, and a power source 15 orientation sensing devices 16, 17, and a controller 18.

[0016] The machine 10 has an articulation joint 19 which divides the machine 10 into a front portion 23, including two wheels 13 and ending in bucket 25, and a rear portion 27, including the controller 18, another two wheels 13, a cabin 28 for an operator, and a rear end 29 behind the two wheels 13 of the rear portion 27 and holding the power source 15. The front portion 23 and rear portion 27 pivot about the articulation joint 19 to effect steering of the machine 10. The orientation sensing devices 16, 17 each measure information which independently may be used to determine the orientation of at least the front portion 23 of the machine 10. For example, one of the orientation sensing devices 16 is a digital compass located on the front portion 23 of the machine 10, forward of the articulation joint 19. The other of the orientation sensing devices 17 is an articulation sensor which measures an angle indicative of other parameter that is indicative of the angle of rotation of the articulation joint 19, and hence indicates the disposition of the front portion 23 of the machine 10 with respect to the rear portion 27 of the machine 10. In the illustrated embodiment, the articulation sensor is located on the rear portion 27 of the machine, adjacent the articulation joint 19.

[0017] Controller 18 is in communication with movement sensors 14, orientation sensors 16, 17, power source 15, and/or drive traction devices 13, and may be configured to regulate operation of power source 15 in response to various inputs, for example, from an operator input device and/or movement sensors 14, to drive the traction devices to propel machine 10 in a desired manner. Controller 18 may also receive information from movement sensors 14 indicative of, for example, velocity, acceleration, and/or turning rate of machine 10, and may be configured to compute various motions, such as distance and direction traversed by machine 10, based on such information.

[0018] Controller 18 includes a processor (not shown), and a memory system (not shown) comprised of a memory module and/or a storage module. Optionally, one or more of the processor, memory module, and/or storage module may be included together in a single apparatus. Alternatively, one or more of the processor, memory module, and/or storage module may be provided separately. The processor may include one or more known processing devices, such as a microprocessor. Memory module may include one or more devices, such as random-access memory (RAM), configured to store information used dynamically by controller 18 to perform

functions related to the various operations of machine 10. The storage module may include any type of storage device or computer readable medium known in the art. For example, the storage module may comprise a magnetic, semiconductor, tape, optical, removable, non-removable, volatile, and/or non-volatile storage device. The storage module may store programs, algorithms, maps, look-up tables, and/or other information associated with determining a position of machine 10 in worksite 20. The functions of both the storage module and memory module may be performed by a single memory/storage device.

[0019] FIG. 2 illustrates machine 10, shown in a simplified manner, performing a task at in worksite 20. Worksite 20 may be any worksite having a roadway 22 traversable by machine 10, but exemplary embodiments are particularly suited to worksites which do not having access to a GPS navigation system. For the exemplary embodiments illustrated herein, worksite 20 is an underground mine site, which does not have access to GPS navigation systems. Roadway 22 is bordered by side walls 24, such as walls of an underground tunnel, and may have a ceiling, such as a tunnel roof (not shown) disposed above roadway 22. In some applications, there may also be objects other than side walls 24 such as other machines, barrels, poles, geological features, and other like obstacles disposed in various locations at worksite 20 relative to roadway and/or the additional objects described above. In various situations, it may be desirable to ascertain position information of machine 10 in worksite 20. The position information may be used to monitor and gather data about how efficiently machine 10 and other machines in worksite 20 are performing various tasks. Additionally, the position information may be used by machine 10 in navigating worksite 20.

[0020] In exemplary embodiments, a position of machine 10 in worksite 20 is determined by utilizing an monitoring system 30. As illustrated in FIG. 2, monitoring system 30 includes, among other things, a processing system 38. The monitoring system 30 further includes a radio frequency communication system 33, as illustrated in FIGS. 2 and 4. The monitoring system 30 determines and tracks the position of the machine 10 at any given time when the machine 10 is in the worksite (or at least operating within an assigned area of the worksite) based at least on the radio-frequency communication system 33. In some embodiments, the determined position includes a coordinate, and optionally an orientation, with respect to a map of the mine which may be stored in a memory system of the monitoring system 30, such as memory system 21 in communication with the processing system 38.

[0021] The radio frequency communication system 33 includes one or more reference signal devices 34, 37 at respective known locations within the worksite 20, and a mobile signal device 36 that is located on the machine. In some embodiments, there may be two, three, or more of reference signal devices 34, 37. As shown in FIG. 2, a first of the reference signal devices 34 is at a corresponding known location 35 within the worksite 20. The first signal device 34 may be fixed to a side wall 24 or ceiling (not shown) of the worksite 20, such as a sidewall 24 or ceiling of the assigned tunnel 113 within which the machine 10 is assigned to operate. A second signal device 36 is located on the machine. In some embodiments, the second signal device 36 is fixed to the rear portion 27 of the machine 10. For example, in one embodiment, the second signal device 36 is located on top of cabin 28, while in another embodiment, the second signal device is located on top of the rear end 29 of the rear portion

27. A third signal device 37, being another of the reference signal devices 34, 37, is attached to the worksite at a different location to the first signal device 34. For example, the third signal device 37 may be fixed to a side wall 24 or ceiling (not shown) of the worksite 20, such as a sidewall 24 or ceiling of the assigned tunnel 113 within which the machine 20 is assigned to operate. The radio frequency communication system 33 is configured to perform a radio frequency communication between the mobile signal device 36 and at least one of the reference signal devices 34, 37.

[0022] Processing system 38 is in communication with one or more of the mobile signal device 36 and reference signal devices 34, 37 of the radio-frequency communication system 33, via at least one communication channel. The processing system 38 may send commands to, and receive data from, the radio-frequency communication system 33 over the communication channel. In one embodiment, the communication channel is or includes a wired communication network 39, such as an Ethernet network, with the reference signal device(s) 34, 37. Alternatively, or additionally, a further communication channel allows the processing system 38 to communicate by a wireless network, eg by at least one WiFi transceiver 40, with the radio-frequency communication system 33. Such a wireless communication can be used to communicate with the mobile signal device 36 in cases where at least part of the processing system 38 is mounted in a fixed position with respect to the worksite (as in FIG. 2), or to communicate with one or more of the reference signal device 34, 37 in cases where the processing system 38 is mounted entirely on the machine 10.

[0023] The processing system 38 may include, or may be, the controller 18. In embodiments, in which the processing system 38 is the controller 18, memory system 21 may include additional data representative of a map of the worksite 20, which may be in addition to or instead of the worksite map stored on memory system 21. The monitoring system 30 may further include a user interface (not shown) having a display panel (not shown) for displaying information to an operator of the monitoring system. In embodiments in which the processing system 38 includes but is not the same as controller 18, processing system 38 may include separate processing device(s), and may use a separate memory system, from the processing device(s) and memory system of the controller 18. In such cases, the processing system may store, outside of controller 18, data representative of a map of the worksite 20. The memory system 21 may be comprised of the same type of components that constitute the controller 18. Similarly, the processing system 38 may include one or more processors in the same manner and types described in relation to controller 18. The processing system 38 obtains data relating to the radio frequency communication from the radio frequency communication system 33. In some embodiments, the obtained data defines a distance associated with a characteristic of the radio-frequency communication. For example, the characteristic may be an time-based characteristic, such as a time-of-flight, associated with the radio-frequency communication. Based on the obtained data relating to the radio frequency communication, the processing system 38 determines position data that is indicative of the position of machine 10 within the worksite 20. The position data indicates the position of the machine 10 within the worksite 20.

[0024] The reference signal device or devices 34, 37 and the mobile signal device 36 may consist of the same hardware and software. However, in some embodiments, especially

involving multiple reference signal devices 34, 37 and/or multiple mobile signal devices 36, each of the reference signal devices 34, 37 and mobile signal devices 36 has a respective device identifier associated therewith, such as unique MAC address. In other embodiments the hardware and/or software of the reference signal devices 34, 37 may be different to that of the mobile signal device(s) 36 by having further differences, in addition to the different device identifiers.

[0025] As described in exemplary embodiments below, the radio-frequency communication 33 is used by processing system 38 to determine position based on a time-based characteristic of the radio-frequency communication. A radial distance to at least one reference signal device 34, 37 may be determined from the time-based characteristic associated with the radio frequency communication. In some embodiments, this radial distance forms the basis of the determined position of the mobile signal device 36 or machine 10.

[0026] In one embodiment, the time-based characteristic is associated with an elapsed time between a transmission of the radio frequency communication and a reception of the radio frequency communication. In one embodiment, the elapsed time is the difference between a time at which a radio-frequency signal is transmitted, in one direction, from one of (i) a reference signal device 34 or 37 or (ii) the mobile signal device 36, and received from the other of the reference signal device 34, 37 or the mobile signal device 36. The transmitted signal includes a time stamp at which the signal was transmitted. The receiving device can therefore determine the time taken for the signal to travel from the transmitter to the receiver. Since the speed of travel is known (ie the speed of light), the radial distance can be determined. However, the internal clock (to which time is measured) on the transmitting device will drift with time with respect to the internal clock on the receiving device. This limits the accuracy with which the travel time, and hence distance and position, can be determined. Therefore, in one embodiment, a wireless synchronization protocol is employed to maintain some synchronicity between the internal clocks.

[0027] In some embodiments, rather than determining an elapsed time, communication system 33 or processing system 38 determines the position of the second signal device 36 by using a time-difference of arrival (TDOA). The time-difference refers to a difference in arrival times for respective signal transmissions between the mobile signal device 36 and a plurality of reference signal devices 34, 37. In this case, the arrival times of the respective signal transmissions are the characteristic upon which the position determination is made. For example a signal may be broadcasted from the mobile signal device 36, and the times of reception (ie arrival) at each of the reference signal devices 34, 37 may be recorded to derive one or more time-difference measurements. Conversely, each of the reference signal devices 34, 37 may simultaneously transmit respective signals, and the arrival time of each of the signals is recorded at the mobile signal device 36. The reference signal devices 34, 37 may be synchronized with each other so that the time difference calculation removes any asynchronicity between the mobile signal device 36 and the reference signal devices 34, 37. Based on the difference in arrival times, the position of the second signal device 36 may be derived.

[0028] In other embodiments, the time-characteristic is an elapsed time relates to a round-trip for a two-way radio frequency communication. An initiating, first radio-frequency signal is transmitted from an initiating device to a responding

receiving device. Upon receiving the first signal, the responding device sends a response radio-frequency signal to the initiating device. In one embodiment, the first signal may include identification data that identifies the initiating device that transmitted the first signal. The response signal may also include the identification data identifying the initiating device. Thus, when the initiating device receives the response signal it can determine that the response signal was a response to the first signal sent by that initiating device, as opposed to some other possible initiating devices in the worksite. The responding device may also include in the response signal identification data that identifies the responding device. Thus, in embodiments having multiple responding devices in the worksite **10**, the initiating device can determine which responding device responded to its initiating signal. From this information, the elapsed time is the time taken for the first signal to propagate from the initiating device to the responding device plus the time taken for the response signal to propagate from the responding device to the initiating device. Processing delays by the initiating device and responding device are constant and may be subtracted or otherwise factored out of any time measurements, and the error due to any clock asynchronicity is eliminated from the elapsed time calculation, since both the transmission time and the reception time are referenced to the same internal clock (ie the clock of the initiating device). The elapsed time may thus represent a two-way time of flight of the radio-frequency communication. The radial distance(s) to the corresponding reference signal device(s) **34**, **37** involved in the radio-frequency communication(s) can be determined as being half of the time-of-flight multiplied by the speed of light.

**[0029]** In one embodiment, the signal transmission involves directional transmission, as opposed to omnidirectional transmission, so that the radial distance corresponds to a specific location in the worksite, as opposed being any point on a circle defined by the radius.

**[0030]** In another embodiment, the specific location along the circle **44** or **46** at which the machine **10** is located may be determined by knowledge of the worksite topology. For example, based on a worksite map stored in memory, the processing system **38**, in determining the position of machine **10**, may exclude locations along the circle **44** or **46** which are not possible locations for the machine **10**. Such excluded locations may be for example locations within a wall of the worksite. Additionally or alternatively, as described above, the processing system **38** can limit the possible locations to those locations on the circle **44** or **46** which are within a tunnel **113** in which the machine **10** is known to be located, eg because it has been assigned to operate in that tunnel.

**[0031]** In addition or as an alternative to using knowledge of the worksite topology, monitoring system **30** also determines a radial distance from a second, third or more reference signal devices **34**, **37** at which the machine **10** is located. The distances from the respective reference signal devices **34**, **37** are used by one of the processing system **38** to determine position by a trilateration process. In the trilateration process, possible position(s) of the mobile signal device **36** is limited to the locations of intersection **47**, **49** of the notional circles **44**, **46** respectively centered the two or more reference signal devices **34**, **37** and having respective radii equal the corresponding determined radial distances. It is appreciated that in the case of two reference signal devices, the trilateration process may be referred to as “bilateration”. However as used

herein “trilateration” is intended to refer to determining location based on the intersection between two or more circles.

**[0032]** In some embodiments, in addition or instead of using the worksite topology information and/or a trilateration process, the accuracy of the position determination may be improved based on a statistical model, such as a Kalman filter. A Kalman filter determines position using an iterative process. Specifically, a Kalman filter determines the most likely position at a time,  $t$ , by using knowledge of one or more past position determinations to weight, based on a likelihood of being correct, all possible positions at time,  $t$ . The possible positions, may be identified by the one or more radial distances to respective one or more reference signal devices **34**, **37**. For example, the statistical model may know the position (or a possible positions) at time  $t-1$ , and know the maximum speed of machine **10**, or a measured change of speed of machine **10**. Based on this knowledge, the statistical model can weight, and then rank, the possible positions at time  $t$  based on their distance and/or directional disposition with respect to the previous position or possible positions at  $t-1$ . For example, those possible positions at time  $t$  which are a further than a first distance from the position or possible positions at time  $t-1$  may be ranked much lower than those possible positions at time  $t$  which are closer than a second distance from the position or possible positions at time  $t-1$ .

**[0033]** In addition to or instead of using a Kalman filter to improve overall position determination as the machine **10** moves in the worksite, a Kalman filter may also be used to improve the accuracy each of the distance measurement used in the position determination. For example, communication system **33** may measure time-of-flight a number of times, by repetitively transmitting round trip communications while the machine **10** is at essentially the same position in the worksite. This may be beneficial in the underground environments due to a level of noise that may result from multi-path reflections or from low a low-signal to-noise ratio. A Kalman filter may in this case be used to improve the distance measurement by disregarding or giving low weighting to measurements that are statistical outliers, and giving higher weighting to measurements which are statistically consistent with previous measurements. Thus, in one embodiment, a first Kalman filter may be used in determining the time-of-flight or distance associated therewith, and second Kalman filter may be used to determine position within the worksite.

**[0034]** In some embodiments, in addition to or instead of using the worksite topology information and/or a trilateration process, the position determination is based on movement information from one or more motion sensors **14**, and/or orientation information from an orientation sensor **16** and/or **17**. In one embodiment, a velocity vector or speed is determined from the motion sensor(s) **14**. For example, one motion sensor **14** may be an odometer, from which a speed is derived. A velocity vector may be derived based on the speed and orientation information, such as may be provided by a digital compass **16**. Since for the described LHD loader, the digital compass **16** provides the orientation of the front portion **23** of the machine **10** only, the orientation of the rear portion **27** of the machine **10** may be derived based on the determined orientation of the front portion **23** and the articulation sensor **17**, measuring the rotation of the rear portion **27** with respect the front portion **23**. The velocity vector or speed can then be used to predict a future position or future set of positions based on a previously determined position or set of possible positions derived from a previous radio-frequency communi-

cation (eg an elapsed time). The set of predicted positions can then be narrowed based on their correlation with a new set of possible positions derived from an updated radio-frequency communication. The parameters in the narrowed set of positions is then updated to new predicted values based on the velocity or speed. This process can be repeated iteratively until only a single predicted position remains, or until the set of positions is narrowed enough to represent an acceptable level of positional accuracy.

**[0035]** The determination of position based on the motion sensors may include a position simulation based on statistical model such as a particle filter. Such a particle filter simulation may include populating a stored map of worksite **20** with one or more virtual particles. Each particle represents a different possible machine position and/or orientation. For example, the position may be represented by an x-coordinate associated with an x-axis and a y-coordinate associated with a y-axis. Orientation of each particle may be represented by degrees of rotation relative to, for example, the positive x-axis, or a two-dimensional unit vector characterized by an x- and y-value. During such a simulation, position system **30** randomly populates a map stored in the memory system **21** with particles. Each particle has an initial randomly generated position and orientation. The respective positions and/or orientations of the particles are then iteratively updated based on information from position data derived from the elapsed time measurements to respective reference signal devices **34**, **37**, until monitoring system **30** is able to determine an accurate position of machine **10** indicated by a spatial convergence of the updated particles.

**[0036]** For any of the above embodiments based on a time-based characteristic, the initiating device(s) and the responding device(s) are Radio-Frequency Ranging (RFR) devices. In one embodiment, the initiating device(s) are respective active (as opposed to passive) RFID tags and the responding device(s) may be respective RFID readers. Alternatively, the initiating device(s) may be respective RFID readers and the responding devices may be respective active RFID tags. However, as a further alternative, the initiating devices and receiving devices are Radio Frequency Ranging (RFR) comprised of the same hardware configuration, but which may be selectively commanded by processing system **38** to initiate the radio-frequency from selected RFR device to any one or more other RFR devices in the RFR system.

**[0037]** The accuracy of the position determination may be improved in a number of ways. In one embodiment, the RFR devices are ultra-wideband (UWB) radio-frequency devices configured to determine a distance between respective devices based on a UWB radio-frequency communication. In some embodiments, the communicated UWB radio-frequency signals have a bandwidth in the order of gigahertz. For example, in one embodiment, the frequencies may range from 3.1 to 5.3 GHz, with a centre frequency of 4.3 GHz, thus providing a bandwidth of approximately 2 GHz. The radio frequency signal transmission may be comprised of a train of pulse waveforms. The pulsed waveforms are short impulses having frequency components that are, in some embodiments, spread over two or more gigahertz. In one embodiment, the spread of frequencies has a centre frequency of around 4 GHz, eg 4.3 GHz. The calculation relating time-of-flight to distance of travel of the radio frequency transmission assumes that the path of transmission is along a straight line. However, in underground mine sites, radio-frequency transmissions are reflected by the rock bed that forms the walls of

the mine tunnels, so the transmission has multiple paths between the transmitter and receiver. The multiple paths result in the signal being received at a multitude of different times, making it difficult to determine the time of the direct, straight path. However, the direct path will arrive first, so can be determined from the leading edge of the received signal, ie the first received pulse. The use of UWB radio-frequencies can improve the resolution of the measurement due to high bandwidth, high frequency composition of the waveform, or put conversely, due to the short wavelength of the signal. In one embodiment, to enable the direct path of transmission to reach the receiver, and be received at an adequate signal strength to accurately detect, the transmitting and receiving RFR devices are arranged in line-of-sight of each other.

**[0038]** In some embodiments, the radio-frequency signal is transmitted and processed for the coherent signal processing. The coherent signal processing involves repetitively transmitting the radio frequency signal in a coherent manner so that same bits of data transmitted via the communication repetitively transmitted over multiple transmissions. This allows the amplitude of the signal transmission to be lower for a given signal-to-noise ratio. The reduced amplitude and hence, power, of the transmission may in some instances be of assistance in ensuring that the radio-frequency communication is within any maximum allowable electromagnetic emission level. This may assist the monitoring system **30** in meeting any regulatory electromagnetic compatibility (EMC) standards which may be required. Additionally or alternatively, the low signal-to-noise ratio can be used to increase, for the same power level, the maximum distance over which the ranging devices may communicate. Accordingly, in some embodiments, the mobile signal device **36** and the reference signal devices **34**, **37** determine a time-of-flight measurement using coherent signal processing. Further, in some embodiments, the coherent signal processing is achieved using UWB radio-frequency ranging devices as the respective signal devices **34**, **36**, **37**, and the time of flight measurement is a two-way (round-trip) time-of-flight measurement. In one embodiment, the UWB coherent processing radio-frequency ranging devices are PulsON® 410 (P410) ranging radio devices manufactured by TimeDomain® (TDC Acquisition Holdings, Inc.). In another embodiment, the UWB coherent processing radio-frequency ranging devices are P412 ranging radio devices, and in a further embodiment, the UWB coherent processing radio-frequency ranging devices are P442 ranging radio devices, also manufactured by TimeDomain®.

**[0039]** In an exemplary embodiment of a two-way time of flight measurement involving coherent processing, a data packet may be transmitted multiple times, at regular intervals (ie a known duty cycle), in a first signal from the initiating device to the responding device. The data packet includes a time stamp indicating the first time that the data is transmitted and an identifier that identifies the initiating device (eg the initiating device's MAC address). The responding device receives the transmission, and identifies the time at which the signal is first arrived at the responding device. The responding device knows the duty cycle at which the data packets are transmitted. Thus the responding device can correlate the packets to integrate corresponding bits within each packet and thereby improve the signal-to-noise ratio. The responding device then determines a one-way time of flight based on the time stamp and the recorded time of arrival. The responding device then sends a response signal to the initiating device using the same repetitive transmission method, but encoding

in the response data packets the time of transmitting the response signal, the calculated one-way time-of-flight, the identifier of the initiating device and an identifier associated with the responding device (eg the responding device's MAC address). The initiating device then receives the response signal and correlates the data from each data packet to improve the signal to noise ratio. The initiating device records the time of first receiving the response signal, and determines the time-of flight for the response signal. The two-way time-of-flight is then derived by the initiating device by summing the time-of-flight of the first signal and the time-of-flight of the response signal.

**[0040]** FIG. 3 illustrates, on a map of worksite mine 20, an arrangement of monitoring system 30. The mine has a plurality of tunnels parallel 113, 115. At a first end of each of the tunnels 113, 115 are respective first signal devices 34, being reference signal devices as described herein. Machine 10, having a mobile, second signal device 36, is assigned to operate a tunnel 113 and portions of the worksite branching therefrom, such as designated loading locations (eg draw-points) for loading ore, and at least one designated dumping location (eg an ore pass) for dumping ore. In some embodiments, the machine 10 is operated to move earth material other than ore, in which case the designated loading and dumping locations may relate to the other earth materials. In some cases, such other materials may be dirt or waste having no intrinsic value, yet it may nonetheless be desirable to determine the activity of the machine in relation to movement of these materials. Each of the designated loading locations and dumping locations are assigned a corresponding unique activity identifier 50, 52, which are mapped to the mine map. Each activity identifier identifies a specific one of the designated locations. The activity identifiers 50, 52 are stored in the memory system of processing system 38. Therefore, the activity identifiers 50, 52 act as virtual identifiers with respect to the stored mine map or other stored geographic frame of reference, such as one or more geographic coordinates. Accordingly, as far as the monitoring system is concerned there is no need for the activity identifiers to occupy physical space in the mine.

**[0041]** The activity identifiers 50, 52 comprise first activity identifiers 50 uniquely identifying each of the designated loading locations, and second activity identifiers 52 uniquely identifying each of the designated dumping locations. Associated with each identifier 50, 52, is a geographic area over which the corresponding designated location is located. Each geographic area may be identified in the memory system of processing system 38. For example the area may be represented by coordinates corresponding to the mine map. In the embodiment illustrated in FIG. 3, these geographic areas are indicated on the mine map as shapes indicated by broken lines. In another embodiment, the area is known by the processing system 38 in terms being within a maximum radial distance from the location associated with the corresponding identifier. In further embodiments, rather than radial distance, the areas corresponding to the designated locations may be represented by other dimensional relationships with respect to the identifier's location or with respect to the mine map. Another machine 11 operates in another tunnel 115 of the mine, although, optionally but not shown, the other machine 11 may operate in the same tunnel 113 as machine 10. Machine 11 may have the same components as machine 10, and like machine 10, and may also be an LHD loader. Machine 11 has a corresponding mobile, second signal device

36 being uniquely identifiable from the mobile device 36 on machine 10 to due to each of the mobile devices 36 having a different serial number, MAC address or some other unique identifier by which the mobile device 36 may be uniquely identified. At a second end of the tunnels 113, 115, opposite the first end, are respective third signal devices 37, being reference signal devices as described herein.

**[0042]** Each of the reference signal devices 34, 37 have a field of operation, within the tunnel, over which the reference signal devices 34, 37 have a line of sight. The field of operation passes at least two of the designated loading locations. In the embodiment of FIG. 3, the field of operation extends at least half way down the corresponding tunnel 113, 115, and optionally, the entire length of the tunnel 113, 115. Each of the reference signal devices 34, 37 are positioned at intersections of the corresponding tunnel 113 or 115 and a cross-road 119 connecting the respective tunnels 113, 115, so the field of operation also includes part of a cross road 119. In this way, the reference signal devices 34, 37 so that mobile machines 10 and 11 are always within a line of sight to at least one, and in one embodiment two, reference signal devices 34, 37. In one embodiment, the reference signal devices 34, 37 are positioned on longitudinal centerlines of their corresponding tunnel. Since the tunnels 113, 115 are relatively narrow, the signal device 36 will be generally collinear with the signal devices 34, 37 at either end of the tunnel. This reduces the position determination to a determination in 1-dimensional space, thus enabling accurate longitudinal position determination by bi-lateralation.

**[0043]** Ethernet network 39 connects the processing system 38 to each of the reference signal devices 34, 37 and, optionally, also to wireless network transceivers 40, in the form of Wi-Fi transceivers, located proximal to a corresponding reference signal device 34, 37. The wireless network transceivers 40 are, in one embodiment, located at the intersection of the corresponding tunnel 113, 115 and crossroad 119. However, in the embodiment illustrated in FIG. 3, the wireless transceivers 40 are located adjacent the intersection, just inside the corresponding tunnel 113 or 115, and have a line of sight meeting the same criteria as for the reference signal devices, so that the mobile signal devices 36 are always within line-of-sight of at least one wireless transceiver 40. The Ethernet network 39 includes an Ethernet switch (not shown) at or next to each of the reference signal devices so that the reference signal devices, and optionally the Wi-Fi transceivers, are connected in a daisy chain topology. In one embodiment, each Ethernet switch is included in a corresponding reference signal devices 34, 37. The Wi-Fi transceivers may be used to send and/or receive operational data to and/or from a Wi-Fi transceivers (not shown) on the respective mobile machines 10, 11. The operational data may for example include information which may be read or entered by an operator of the mobile machine via a user-interface module (not shown) in communication with the Wi-Fi transceiver on the mobile machine 10, 11.

**[0044]** The respective positions of the machines 10, 11 in the worksite 20 may be determined based on radio-frequency communication in accordance to any method and on any system described herein. However, in one embodiment, particularly suited to the arrangement of monitoring system 30 in FIG. 3, reference signal devices 34, 37 are UWB radio-frequency ranging devices having features and operation as has been previously described.

[0045] The position of the second signal device infers the position of the machine 10 at the part of the machine 10 at which the second signal device 36 is mounted. In some embodiments, the second signal device is mounted on the rear portion 27 of the machine 10. This is because when the machine 10 is in a drawpoint or ore pass, the rear portion of the machine remains in the tunnel 113, 115 from which the drawpoint or ore pass is accessed. By keeping the second signal device 36 within the tunnel 113, 115, a line-of-sight communication can be maintained between the second signal device 36 and at least one of the reference signal devices 34, 37. Thus, for any operational position of the machine 10, the monitoring system 30 maintains (or may obtain) positional knowledge concerning the current position of the machine 10 from the signal devices 34, 36, 37.

[0046] An exemplary method 200 for determining an activity associated with a machine, in accordance with the present disclosure, is illustrated in FIG. 4. At step 202, monitoring system 30 performs a radio-frequency communication between reference signal device 34 at a known location and a mobile signal device 36 on the machine 10. In some other embodiments, the communication involves one or more round-trips between the mobile signal device 36 and the reference signal device 34. In the case of the communication involving at least one round trip, at step 204 a first radio frequency signal is transmitted from an initiating device, being one of the first reference signal device 34 and mobile signal device 36, to the responding device, the responding device being the other of the first reference signal device 34 and the mobile signal device 36. At step 206, after receiving the first signal, the responding device transmits a response signal back to the initiating device. The initiating device, upon receiving the response signal determines the position of the machine 10 in a manner as described herein, based on a time-of-flight. In other embodiment, the radio-frequency communication at step 202 is a one-way communication. In this case, the position may be determined based on some other time-based metric such as time-difference-of-arrival, provided positioning system 30 takes into account an arrival time with respect to a communication between the mobile device and a further reference signal device 37, as described herein. In either case, the position of the second ranging device 36 and thus machine 10, is determined in step 210, based on at least on a time-based characteristic associated the radio-frequency communication. At step 218, the processing system 38 identifies an activity of the mobile machine 10 based on a positional correlation between the determined position of the mobile machine 10 and one of a plurality of activity identifiers associated with respective positions in the mine 20. In addition to identifying a type of activity, the monitoring system 30 may identify the location associated with the activity. The monitoring system 30 may further identify a time or time period at which the activity is determined to have occurred. The positional correlation is determined with respect to a geographic frame of reference (eg the worksite map) stored in the memory system 21. In one embodiment, the processing system 38 of the monitoring system is configured to display the worksite map, the activity identifiers, and the determined position of the machine 10 on the display panel of the user interface, for example, as illustrated in FIG. 3.

[0047] There will now be described exemplary embodiments for determining an activity associated with machine 10, based on the determined position of the machine 10. In

some of these embodiments, the activity determination is more specifically based on position of a portion of the machine.

[0048] In some embodiments, processing system 38 determines or infers the position of the front bucket 25 of the front portion 23 of machine 10 based on the determined position of the second signal device 36, and an inferred position of the rear portion 27 of the machine 10. The position of the front bucket 25 may be determined by using the orientation information from the digital compass 16 and/or articulation sensor 17 to determine the position of the front bucket 25 with respect to the second signal device 36. In one embodiment, the monitoring system 30 determines that the machine 10 is in a drawpoint or ore pass if: (i) the articulation sensor indicates that the front portion 23 (and therefore the bucket 25) of machine 10 is rotated by more than a threshold angle with respect the rear portion of the machine; and (ii) the position of the second signal device 36 is adjacent an ore pass or drawpoint. This conclusion is derived from an assumption in some situations that, for the machine 10 to access the ore pass or drawpoint, the machine 10 must be oriented in a sufficiently bent manner. Accordingly it is concluded that the bucket 25 is positionally correlated with the ore pass or drawpoint adjacent the machine. In one embodiment the threshold angle is 25 degrees. In some embodiments, this bent orientation is required due the tunnel being relatively narrow, which limits the range of positions of the machine 10 from which the ore pass or drawpoint may be accessed. By contrast, if the articulation sensor 17 indicates that the rotation is less than the threshold angle, the monitoring system 30 determines that the orientation of the machine 10 is substantially straight, or at least not sufficiently bent to indicate loading or dumping at a drawpoint or ore pass.

[0049] In other embodiments, the position of mobile signal device 36 may be combined with historical data regarding the orientation of machine 10 in order to determine the correlation with an activity identifier 50, 52. This may be useful in instances where the machine 10 turns to enter a designated activity location, but has straightened up by the time the machine 10 reaches a positional correlation with the associated activity identifier 50, 52. Recent orientation data indicating the turn may be used in this case to infer the positional correlation of the bucket 25 with the activity identifier.

[0050] In some positions along the tunnel 113 there are more than one designated loading or dumping locations for the same longitudinal position along the tunnel 113. For example, for the same position along the tunnel's length, there may be two drawpoints 54, 56, one each side of the tunnel. Drawpoint 54 is on the left side of the tunnel 113 as the machine 10 drives along a longitudinal centerline of the tunnel 113, along path 90, toward reference end 91 of the tunnel 113. The other drawpoint 56 will be on the right side of the tunnel 113 as the machine drives towards the reference end 91. In FIG. 3, drawpoints 54 and 56 are slightly offset from each other, with respect to the longitudinal axis of tunnel 113. However, for the position of the second signal device 36, the bucket 25 of machine 10 could potentially be in either of the drawpoints 54 or 56, depending on the rotation at the articulation joint 19. Further, in some mines, drawpoints on either side of a tunnel may be directly opposite each other, ie with no longitudinal offset, making it harder to distinguish which drawpoint the machine 10 is positionally correlated with.

[0051] The uncertainty over which side of the tunnel 113 the bucket is located may, in some cases, be exacerbated if the

monitoring system 30 is unable to sufficiently determine the position of the second signal device 36 across the tunnel 113, ie how the second signal device 36 or machine 10 is positioned laterally from the longitudinal centerline of the tunnel 113. For example, with one reference signal device 34 at one end of tunnel 113, and one other reference signal device 36 at the other end of tunnel 113, positioning based on the radio-frequency communication alone may not provide sufficient accuracy or positional resolution to determine the lateral position.

[0052] One way to determine the lateral position is to use a time-of-flight or time of arrival measurement (the latter being for a time-distance of arrival measurement) associated with a reference signal device located in an adjacent tunnel 115. However, a reference signal device from an adjacent tunnel 115 will not have a line of sight to the second signal device 36 of machine 10, so the measurement may be unreliable. However, based on the determined position of the second sensing device 36 and the angle and direction of rotation of the articulation joint 19, as measured by articulation sensor 17, monitoring system 30 can conclude which of the left or right drawpoints 54 or 56 the bucket 25 is positionally correlated with, based on their respective positions as indicated by their associated activity identifiers 50. If the angular orientation indicated by articulation sensor 17 is very small (ie the machine 10 is substantially straight), monitoring system 30 can conclude that the bucket 25 is somewhere between but not in the drawpoints 54, 56. Put another way, bucket 25 is not positionally correlated with either of the drawpoints 54, 56.

[0053] By determining whether the machine is positionally correlated with an activity identifier, the monitoring system 30 can also infer instances when the machine is inactive, which may indicate a fault with the machine or a problem experienced by an operator (i.e. a person) on the machine. Typically, if the machine 10 is stationary for longer than some short period of time, eg 10 seconds, it may be concluded that the machine 10 is either loading ore, dumping ore or is inactive. However, when the machine is near a loading or dumping location it may be difficult to determine whether the machine is inactive or, alternatively, loading or dumping. However, when the machine 10 is not loading or dumping it should be moving between loading and dumping locations. Taking this into account, in one embodiment, monitoring system 30 determines that the machine is in an inactive state if the machine 10 is stationary for longer than the predetermined time-period, eg 3 minutes, while the mobile machine is not positionally correlated with a first or second position identifier 50, 52 for loading or dumping. The monitoring system 30 may indicate to an operator of the monitoring system 30 that an inactive status has been determined, so that the operator may act in response to the inactive status determination. In some applications loading and dumping activities only take 10-20 seconds. In such applications monitoring system 30 may determine an inactive status if the machine 10 is correlated with a loading or dumping activity identifier for longer than a predetermined period of time, eg 5 minutes, as this may indicate a problem with the machine 10.

[0054] Additionally, or alternatively to using the orientation information from the articulation sensor 17, the positional correlation can be determined from the position of the second sensing device 36 and orientation information from digital compass 16. Digital compass 16 measures the orientation, in terms of direction, along which the front portion 23 of machine 10 is aligned. By tracking the position of machine

10, which generally travels in a forward direction, the monitoring system 30 can determine the orientation of the rear portion 27 of machine 10, on which second signal device 36 is mounted. As an alternative to assuming that the machine travels in the forward direction, the monitoring system 30 may determine whether the machine 10 is moving forward or in reverse along tunnel 113 based on information from the motion sensing device 14. Knowing the orientation of the rear portion 27 and the orientation of the front portion 23, monitoring system 30 can determine whether the bucket 25 is positionally correlated with any activity identifiers 50, 52 respectively identifying the positions of the designated loading or dumping location(s), either side of the tunnel 113.

[0055] For example, in the embodiment illustrated in FIG. 3, the tunnel runs from a south-west end to a north-east end (reference end 91). It may be known, eg by tracking movement of machine 10, that the rear end 29 of rear portion 27 is facing south west. If the directional orientation of the front portion 23 is north-south aligned, it may be concluded that the bucket 25 is positionally correlated with a designated dumping/loading location on the left or western side of the tunnel, as shown in FIG. 3, illustrating the bucket 25 being positionally correlated with the north-western drawpoint 54. On the other hand, if the digital compass 16 indicates that the front portion 23 is east-west aligned, monitoring system 30 can conclude that the bucket 25 is positionally correlated with south-eastern drawpoint 56.

[0056] The orientation information in terms of both directional orientation (from digital compass 16) and angular orientation (from articulation sensor 17) can be used to determine the precise location of the bucket 25 with respect to the mine map, for a determined position of second signal device 36 or the machine 10 to which the second signal device is mounted. Alternatively, the precise location of the bucket 25 with respect to the mine map can be determined based on the information from either one of the digital compass 16 and articulation sensor 17, by taking into account the how the current position of machine 10 and how the machine's position along tunnel 113 has changed with time (eg by using a particle filter or Kalman filter or any other position tracking method). The position of the front bucket 25 is derived with respect to a map of the mine which is stored in a memory system of the processing system 38. In one embodiment, the position is stored as a coordinate, such as an x (eg north/south) and y (eg east/west) coordinate, with respect to the map of the mine. In other embodiments the position may be stored a memory address which corresponds to a particular position on the map. The positional correlation of bucket 25 with respect to any one or more the activity identifiers 50, 52 for the designated loading and dumping locations can then be calculated or otherwise determined.

[0057] In one embodiment, the distance from the bucket 25 to any or all of the positions associated with the activity identifiers 50, 52 is calculated by measuring the distance between x and y positional coordinates of the bucket 25 and x and y positional coordinates for the respective activity identifiers. If the distance with respect to any one activity identifier is less than a threshold distance, eg 3 meters, then the bucket is determined to be positionally correlated with that activity identifier. Accordingly, the activity performed by machine 10 is then determined to be the activity associated with the activity identifier.

[0058] In another embodiment, as indicated in FIG. 3, each activity identifier is associated with a specific area, which is

indicated on, or with respect to, a map of the mine. In FIG. 3, each of these areas are illustrated by triangular shapes. However, any shape may be used to indicate the area associated with an activity identifier 50, 52. In one embodiment, if the position of the bucket 25 is within the area associated with an activity identifier, then the machine 10 is then determined to be performing the activity associated with the activity identifier. In some cases, the activity may be performed if the bucket is partially within the area. For such cases, monitoring system 30 is configured to minimize false activity determinations by determining how much of the bucket is within the area and makes a decision on the whether the activity is being performed based on a threshold area measurement. For example, the machine may be determined to be performing the activity if minimum percentage or amount of the bucket 25 is within the area associated with the activity identifier 50, 52. In another embodiment, positioning system 30 determines if two points on the machine 10 (eg two points on the front of the bucket) are within the area.

[0059] In further embodiments the mobile machine 10 may be a truck (not shown) that operates in a truck level or haulage layer (not shown) of the mine 20. The truck may have the same features as the LHD loader, but might not have an articulation joint 19 or articulation sensor 17. Alternatively, the truck may have an articulation joint 19 and articulation sensor 17, but the joint 19 and sensor 17 might not be of assistance in identifying the truck's activity. Like the case of an LHD loader, the truck may have a bucket 25 adapted for carrying ore. Alternatively, in place of bucket 25, some other portion of the truck may be adapted for carrying ore, eg a rear portion of the truck. The system 30 may thus determine the activity of the truck based on the positional correlation of the bucket 25 (or some other portion of the truck for carrying ore) and an activity identifier in the mine 20. In this case the first activity identifiers 50, corresponding to a designated loading location, may be associated with a corresponding chute that receives ore from an associated orepass. Second activity identifiers 52, corresponding with designated dumping locations, may be associated corresponding crushers.

[0060] Regardless of whether the mobile machine (10) is an LHD loader, a truck or some other vehicle, in some embodiments, the positional correlation between the mobile machine 10 and an activity identifier 50, 52 may be determined without reference to the orientation of the machine 10 or the portion of the machine 10 for carrying ore. For example, in one embodiment, if the entire mobile machine 10 is determined to be within an area defined by an activity identifier, system 30 determine that the machine is performing the activity associated with the positionally correlated activity identifier. In other embodiments the positional correlation with the activity identifiers may be determined with respect to the second signal device 36, alone. Thus, in such cases the orientation of the machine 10 need not be considered. Such embodiments may be employed especially in cases where an activity identifier corresponds to a relatively large, spread out area, in comparison with the size of the machine 10.

[0061] In further embodiments, the orientation of machine 10 may be utilized to determination the positional correlation of the machine with an activity identifier but the orientation is derived by tracking the movement of the mobile signal device 36 on the mobile machine. The orientation of the mobile machine 10 can then be inferred based on the movement of the mobile signal device 36 and known behaviors of the machine 10 and/or limitations on the machine's locomotion.

[0062] In addition to loading and dumping activity identifiers 50, 52, other activity identifiers may be used by monitoring system 30. For example, an activity identifier may correspond with a parking bay to allow for identification of the machine 10 as being in a "parked" activity state when it is in the parking bay. In other example, the activity identifier may correspond with a workshop for identifying when the machine is in a non-operational state, and undergoing repairs, modifications or servicing.

[0063] Monitoring system 30 can also determine the activity of the machine 10 based on the determined position of the machine, taking into account a previously determined activity or previous correlation between the mobile machine (or a portion thereof) and an activity identifier. For example, if the machine position had been correlated with a loading location, and the machine's position is subsequently determined to be moving away (or to have moved away) from the loading location 50, the monitoring system 30 may determine the machine's position to be 'travelling full', ie travelling full of ore or other earth material, as the case may be. Similarly, when the position of the machine is determined to be travelling away from (or to have just left) a designated dumping location 52, the monitoring system 30 may determine the machine's activity to be 'travelling empty', since it can be assumed that the machine 10 has just emptied its contents at the dumping location 52. When the monitoring system has determined that the machine 10 has been travelling empty, loaded, traveled full, dumped, the monitoring system can determine that the machine 10 has completed a cycle. Such cycles may be accumulatively tracked by the monitoring system.

## INDUSTRIAL APPLICATION

[0064] FIG. 5 illustrates a method 220, which is an embodiment of the method 200. Steps 202, the communication system 33 performs an ultra-wideband radio-frequency communication. The communication involves, at step 224, repetitive transmission of data packets from an initiating signal device (a reference signal device 34, 37 or the mobile signal device 36) to a responding signal device (the other of reference signal device 34, 37 or the mobile signal device 36). The data packets are coherently processed at the responding device to determine the propagation time (time-of-flight) from the initiating device to the responding device. At step 206, the responding device then repetitively transmits a response packet back the initiating device, which coherently processes the response packet to determine the propagation time from the response device to the initiating device. The initiating device, then sums the determined two propagation times to determine a two-way time of flight at step 228. The two-way time of flight is determined for a plurality of round-trip communications and fed into a Kalman filter (not shown) to improve the accuracy of the two way time of flight measurement. From the Kalman filter's time-of-flight measurement, a distance measurement is derived and fed into a statistical filter at 229 which determines the position of the mobile signal device 36 with respect to the mine 20, based on the distance measurement and the known location of the reference signal device 34, 37 associated with the distance measurement. The communication system repeats steps 224 to 208 to derive further distance measurements for subsequent positions of the machine 10. In one embodiment, the statistical filter is another Kalman filter. Based on these iteratively derived distance measurements the Kalman filter deter-

mines the position of the machine 10, at step 230. In an alternative embodiment, the statistical filter is a particle filter, which receives the iteratively derived distance measurements and also orientation information from an orientation sensing device 16, 17 to derive the position of the machine 10. At step 236, the processing system 38 evaluates the positional correlation between the machine (or ore-carrying portion thereof, such as bucket 25) with activity identifiers to identify whether there is an activity identifier that is positionally correlated with the machine 10 or portion thereof. If the machine is positionally correlated with an activity identifier, the processing system 38 determines that the machine is performing the activity associated with the correlated activity identifier, at step 238. The communication system 30 continues to perform radio-communications to track the position of the machine as it moves in the mine and identify further activities as the machine moves into a positional correlation with further activity identifiers.

[0065] In some embodiments, monitoring system 30 need not indicate or record which specific machine in the mine performed the activity. Rather, the monitoring system 30 may merely indicate, or record in a memory system, that the activity has been performed. For example, if a machine is involved in a loading activity, monitoring system 30 might only record that the activity of loading ore has occurred and, optionally record the specific loading location from which the ore was loaded. Similarly, if a machine is involved in a dumping activity, the monitoring system 30 may also record that ore has been dumped, and optionally record the dumping location at which the dumping occurred. Such information may be used, for example, to track the movement of ore within the mine.

[0066] By using a time based characteristic to determine the position of machine 10, the machine's position can be tracked even when the machine 10 is outside of the designated loading or dumping locations. The use of a time-based characteristic may allow the machine 10 to be relatively accurately determined and/or tracked using referencing hardware (reference signal devices 34, 37) located at one or both ends of the tunnel. It can thus be determined when the machine 10 is at a designated loading/dumping location without requiring RFID hardware to be installed and maintained at the designated loading/dumping locations. Furthermore, the tracking function enabled by the time-based position determination enables other activity states of the machine to be determined when the machine 10 is not at a designated loading/dumping location.

[0067] It will be understood that the disclosure in this specification extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the disclosure.

What is claimed is:

1. A method for determining an activity associated with a mobile machine in an underground mine, the method comprising:

communicating by a radio-frequency communication between a first ranging device at a known location within the mine and a second ranging device located on the mobile machine;

determining a position of the mobile machine based at least on a time-based characteristic associated with the radio-frequency communication; and

identifying an activity of the mobile machine based on the determined position in the mine.

2. A method according to claim 1, wherein identifying the activity is based on a positional correlation between the determined position and an activity identifier from a plurality of activity identifiers associated with respective positions in the mine.

3. A method according to claim 2, wherein the determined position of the machine is a position of a portion of the mobile machine for carrying earth material; and

determining the position of said portion of the mobile machine is based on said time-based characteristic and on orientation information associated with said portion, the orientation information being derived from at least one orientation sensing device located on the mobile machine.

4. A method according to claim 2, wherein the plurality of activity identifiers comprise:

one or more first activity identifiers corresponding to respective positions in the mine which are designated for loading earth material; and

wherein in the event that said determined position of the mobile machine positionally correlates with a first activity identifier, the activity is determined to be loading of the earth material.

5. A method according to claim 4, wherein the method further comprises tracking movement of the mobile machine based on a time-based characteristic associated with subsequent radio frequency communications between the first and second signal devices; and

wherein the plurality of activity identifiers further comprise one or more second activity identifiers corresponding to respective positions in the mine which are designated for dumping the earth material; and in the event that a determined position of the mobile machine positionally correlates with a second activity identifier, the determined activity is dumping of the earth material.

6. A method according to claim 5, wherein in the event that the mobile machine is stationary for longer than a predetermined time-period while said position of the mobile machine is not positionally correlated with a first or second position identifier, the mobile machine is determined to be inactive.

7. A method according to claim 1,

wherein the radio frequency communication comprises at least one round trip, each of the at least one round trips comprising:

transmitting a first radio frequency signal from one of first and second ranging devices, the first ranging device being at a known location in the mine and the second ranging device being on the mobile machine; and

receiving a radio frequency response signal from the other of the first and second ranging devices;

wherein the characteristic is a two-way time-of-flight.

8. A method according to claim 7, transmitting a first signal and transmitting a response signal each comprise transmitting data multiple times, wherein the data is coherently processed to determine the time of flight.

9. A method according to claim 7, wherein the method comprises determining the position from a plurality of determined two-way time-of-flights, for respective round-trip communications, using a Kalman filter.

10. A method according to claim 1, wherein determining the position of the mobile machine is further based on information derived from a motion sensor.

11. The method of claim 7, wherein determining the position of the mobile machine is further based on information derived from a motion sensor, and wherein the position is determined from a plurality of determined time-of-flights, wherein the position is derived using a particle filter.

12. The method of claim 1, wherein the radio-frequency communication is an ultra-wideband radio-frequency communication.

13. The method of claim 1, wherein the method further comprises:

performing a radio-frequency communication between the second ranging device and a third ranging device, the third ranging device being at another known location in the mine; and

determining the position of the mobile machine is additionally based on a time-based characteristic associated with the radio frequency communication between the second and third ranging devices.

14. A system for determining an activity associated with a mobile machine in an underground mine, the system comprising:

a first ranging device for positioning at a known location in the mine and a second ranging device for attaching to the mobile machine, the first and second ranging devices being configured to perform a radio-frequency communication therebetween;

a memory system for storing data defining a geographic frame of reference; and

a processing system configured to:

determine a position of the mobile machine based at least on a time-based characteristic associated with the radio-frequency communication; and

identify an activity of the mobile machine based on the determined position in the mine by determining a positional correlation between the determined position of the mobile machine and an activity identifier from a plurality of activity identifiers associated with respective positions in the mine, the positional correlation being determined with respect to the stored data defining a geographic frame of reference.

15. A system according to claim 14, wherein identifying the activity comprises is based on a positional correlation between the determined position of the mobile machine and said activity identifier from a plurality of activity identifiers.

16. A system according to claim 14, wherein:

the system further comprises an orientation sensing device located on the mobile machine for determining orientation information associated with a portion of the mobile machine for carrying the earth material;

the determined position of the machine is a determined position of said portion of the mobile machine; and

the processing system is configured to determine the position of said portion of the mobile machine based on said time-based characteristic and on the orientation information associated with said portion of the mobile machine.

17. A system according to claim 15, wherein the plurality of activity identifiers comprise:

one or more first activity identifiers corresponding to respective positions in the mine which are designated for loading earth material; and

wherein in the event that said determined position of the mobile machine positionally correlates with a first activity identifier, the activity is determined to be loading of the earth material.

18. A system according to claim 17, wherein the plurality of activity identifiers further comprise one or more second activity identifiers corresponding to respective positions in the mine which are designated for dumping the earth material; and

the processing system is further configured to track movement of the mobile machine based at least a time-based characteristic associated with subsequent radio frequency communications between the first and second signal devices;

wherein in the event that a determined position of the mobile machine positionally correlates with a second activity identifier, the activity is determined to be dumping of the earth material.

19. A system according to claim 14, wherein the first ranging device and second ranging device are ultra-wideband ranging devices, and the characteristic is a two-way time-of-flight.

20. A method for determining a plurality of activities associated with a mobile machine in an underground mine, the method comprising:

performing a first radio-frequency communication comprising at least one round trip communication, each of the at least one round-trips comprising:

transmitting a first radio frequency signal from one of first and second ranging devices, the first ranging device being at a known location in the mine and the second ranging device being on the mobile machine; receiving a radio frequency response signal from the other of the first and second ranging devices;

determining a first position of the second ranging device based at least on a time-of-flight associated the first radio-frequency communication;

receiving first orientation information associated with a bucket portion of the mobile machine from an orientation sensing device located on the mobile machine;

determining a first activity based on the determined position and the received first orientation information; and

performing a second first radio-frequency communication comprising at least one round trip communication, each of the at one least round-trips comprising:

transmitting a second radio frequency signal from one of second and third ranging devices, the third ranging device being at another known location in the mine; receiving a second ultra-wideband radio frequency response signal from the other of the second and third ranging devices;

determining a second position of the second ranging device based at least on a time-of-flight associated with the second radio-frequency communication;

receiving second orientation information associated with the bucket from the orientation sensing device located on the mobile machine;

determining a second activity based on the second determined position and the received second orientation information.

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