Title
Navigation of mining machines

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ABSTRACT

This disclosure relates to a mining machine comprising a machine controller comprising a control output port for a machine control signal that controls movement of the mining machine and an inertial navigation system (INS). The INS comprises a position determination unit determining a position of the mining machine, and an input port for an input signal indicative of the movement of the mining machine, the input port being communicatively coupled to the position determination unit. The control output port of the machine controller is communicatively coupled to the input port for the input signal of the INS to allow the position determination unit to calculate a corrected position of the mining machine based on the machine control signal that controls the movement of the mining machine.
Fig. 2a

Fig. 2b
"Navigation of mining machines"

Cross-Reference to Related Applications

[1] The present application claims priority from Australian Provisional Patent Application No 2015903107 filed on 4 August 2015, the content of which is incorporated herein by reference.

Technical Field

[2] This disclosure relates to mining machines that use inertial navigation systems and methods for determining the position of a mining machine that uses an inertial navigation system.

Background

[3] Fig. 1a illustrates an underground coal mine 100 that follows a room and pillar layout. A coal seam 102 is mined by removing coal from the seam 102 while keeping pillars, such as pillar 104, to support the mine roof (not shown). A continuous miner 106 advances into the seam 102 between new pillars 108 and 112. A coal hauler 112 transports the coal mined by the continuous miner 106 to a belt system, which, in turn, transports the coal towards the surface.

[4] In order to achieve a planned room and pillar layout and to follow the coal seam 102, which may be inclined or tilted, it is important that the continuous miner 106 utilises accurate navigation systems such that an accurate position can be determined while mining.

[5] However, external navigation signals, such as GPS signals, are absorbed by the strata and therefore not available to the continuous miner 106 underground. Instead, inertial navigation systems can be used underground. But as they rely on integration of the sensor signal they suffer from drift errors over time, which makes the determined position inaccurate.
Fig. 1b illustrates the control flow of continuous miner 106. Continuous miner 106 comprises a positioning system 152 to generate control signals 154, such as a brake signal, as an output of the positioning system 152. Continuous miner 106 further comprises multiple external sensors 156, such as odometer, steering angle and gps sensors. The sensors 156 generate sensor signals 158 as an input to the positioning system 152. Positioning system 152 comprises an inertial navigation system that performs a zero velocity update when the sensor signals 158 at the input of the positioning system 152 indicate that the continuous miner 106 is stationary. Using the sensor signals 158 as an input to generate the control signals 154 at the output reduces the inaccuracies caused by the drift in the inertial navigation system. However, the sensors 156 are often inaccurate. For example, it is often difficult to distinguish between very slow speed and standstill based on the odometer signal. Further, the additional sensors 156 increase the complexity of the machine 106, which reduces reliability.

US 8,700,324 discloses the detection of malfunctioning of a navigation unit, such as an inertial navigation unit. A controller receives machine parameters from sensors, such as speed and heading, determines an estimated position and compares the estimated position to the position from the navigation unit. The sensors include steering angle, speed, pitch, roll and yaw sensors. The controller may control manoeuvring (i.e., propulsion, steering, and/or braking) of the machine. This solution also suffers from the problem that the sensors are often inaccurate and that the additional sensors increase the complexity of the machine, which reduces reliability.

Reid, D. C. et al., 'A practical inertial navigation solution for continuous miner automation', 12th Coal Operator's Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2012, pages 114-119 discloses zero velocity updating of an inertial navigation unit using odometer sensor data. Again, the odometer is often inaccurate and the additional sensor increases the complexity of the machine, which reduces reliability.
[9] Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it existed before the priority date of each claim of this application.

[10] Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

Summary

[11] A mining machine (100) comprises:
   a machine controller (102) comprising a control output port (104) for a machine control signal (106) that controls movement of the mining machine (100); and
   an inertial navigation (108) system comprising
      a position determination unit determining a position of the mining machine (100), and
   an input port (110) for an input signal indicative of the movement of the mining machine (100), the input port being communicatively coupled to the position determination unit,
   wherein the control output port (104) of the machine controller (102) is communicatively coupled to the input port (110) for the input signal of the inertial navigation system (108) to allow the position determination unit to correct the position of the mining machine (100) based on the machine control signal (106).

[12] It is noted that in the above machine, the machine control signal is used as an input of the inertial navigation system. This is in contrast to other machines where the inertial navigation system generates the machine control signal as an output and not as an input. More particularly, previous positioning systems are used to control the mining machine processes, such as by generating an output control signal to control
the brakes, traction, or other subsystems of the mining machine. The accuracy of such a positioning system may also depend on additional sensors providing an input to the positioning system.

[13] The proposed machine provides an improvement to existing machines by increasing the accuracy of the positioning system using the control status of the machine as an input to the positioning system, and reducing complexity by removing the need for external sensors, such as odometers, and infrastructure based position aiding techniques.

[14] Since the above inertial navigation system uses a machine control signal, the inertial navigation system can perform the correction at times where the machine stops for any reason. This is an advantage of other methods where the machine is stopped for the particular purpose of performing a zero-velocity update because less extra stops are required. Further, the overall system is less complex than other systems using sensors, such as odometers, because no additional detection of zero velocity intervals is required. The accuracy of the proposed system is improved to less than 1% and preferably less than 0.5% of the distance travelled rather than multiple nautical miles per hour of operation as seen in prior art systems.

[15] The mining machine may be a continuous miner.

[16] The arrangement of using machine control signals for zero velocity updates is particularly advantageous for continuous miners as they stop frequently for the mining process, including roof bolting. The mining machine may further comprise one or more sensors of a machine state, each sensor comprising a sensor output for a sensor output signal, wherein the sensor output signal of each of the one or more sensors is isolated from the input port for the input signal of the inertial navigation system.

[17] The one or more sensors of a machine state may comprise an odometer and the sensor output signal of the odometer may be isolated from the input signal of the inertial navigation system.
The machine control signal may comprise a braking signal.

The machine control signal may comprise a motor control signal.

The motor control signal may comprise an ignition circuit breaker signal or a control signal for an electric motor.

The mining machine may further comprise a signal bus electrically coupled to the control output port and the input port to transmit the machine control signal.

The inertial navigation system may comprise a motion sensor to set the inertial navigation system to a moving state while the machine control signal indicates the mining machine is stationary.

The inertial navigation system comprises a motion sensor and a logical AND module to set the inertial navigation system to a stationary state where the zero velocity update is performed when both the machine control signal and the motion sensor indicate the mining machine is stationary.

The inertial navigation system may comprise a fiber-optic gyroscope.

A method for determining a position of a mining machine comprises:
  determining an initial position of the mining machine;
  determining an updated position of the mining machine based on the initial position and based on data from one or more inertial sensors; and
  determining a corrected position of the mining machine,
wherein determining the corrected position is based on a machine control signal that controls movement of the mining machine.

Determining the corrected position may comprise performing vehicle motion sensor aiding.
The machine control signal may be indicative of a velocity of the mining machine and performing vehicle motion sensor aiding comprises determining the corrected position based on the velocity of the mining machine as indicated by the machine control signal.

Performing vehicle motion sensor aiding may comprise performing zero velocity updating.

Performing zero velocity updating may comprise determining whether the mining machine is stationary based on the machine control signal and performing the zero velocity update upon determining that the mining machine is stationary.

Determining that the mining machine is stationary may comprise determining that the machine control signal indicates that the mining machine is stationary and that a motion sensor indicates that the mining machine is stationary.

Software, when installed on a computer, causes the computer to perform the above method.

Optional features described of any aspect of the continuous miner, method, software, computer readable medium or computer system, where appropriate, similarly apply to the other aspects also described here.

**Brief Description of Drawings**

Fig. 1a illustrates an underground mine (prior art).

Fig. 1b illustrates the control flow of the continuous miner of Fig. 1a.

An example will be described with reference to:

Fig. 2a illustrates a continuous miner.

Fig. 2b illustrates the control flow of the continuous miner of Fig. 2a.

Figs. 3a to 3c illustrate a work cycle of the continuous miner of Fig. 2a.

Fig. 4 illustrates a internal communications network of the continuous miner.
in Fig. 2a.

Fig. 5 illustrates the structure of the INS in Fig. 2a in more detail.

Fig. 6 illustrates a method for determining a position of a mining machine.

**Description of Embodiments**

[35] Fig. 2a illustrates a continuous miner 200 comprising a machine controller 202 comprising a control output port 204 for a machine control signal 206. The machine control signal 206 controls movement of the mining machine 200. In other words, the machine control signal 206 causes or instructs actuators of the machine to perform their respective actions. This means, the control signal 206 actively causes a change of state of the continuous miner 200. For example, the machine control signal 206 provides commands to the mining machine 200. The command may be analog, such as a high voltage on a wire to activate the brakes. Alternatively, the command may be digital, such as a data packet on a CAN bus. The meaning of control signal 206 is in contrast to the meaning of sensor signals, which passively detect the state of the continuous miner 200 but cause no action or change of state of the continuous miner. In some examples, the machine control signal 206 is indicative of a desired or intended state of the continuous miner 200 while the sensor signals are indicative of a measured state of the continuous miner 200. The continuous miner 200 further comprises an inertial navigation system (INS) 208, which, in turn, comprises a position determination unit 209, such as a processor or microcontroller, determining a position of the mining machine 200 and an input port 210 for an input signal indicative of the movement of the mining machine 200.

[36] Any reference to ‘position’ herein may refer to a three-dimensional position comprising x, y and z coordinates, that is, longitude, latitude and altitude or coordinates relative to the reference frame of the mine 100. The position may also comprise attitude comprising three rotation angles. That is, the position of continuous miner 200 may comprise six values for the six degrees of freedom.
[37] Mining machine 200 further comprises a propulsion system 212, such as a track drive, crawlers or driven wheels and a braking system 214 mechanically coupled to the propulsion system 212 to inhibit movement of the mining machine 200 relative to the ground when the braking system 214 is activated by an appropriate machine control signal 206.

[38] Mining machine 200 further comprises a rotating cutting drum 216 with fitted picks supported by a boom 218. A loading shovel 220 catches the coal that is cut by cutting drum 216 and transports the coal onto a conveyor 222 from where the coal is received by hauler 112 in Fig. 1a.

[39] The input port 210 of the INS 208 is communicatively coupled to the position determination unit 209 and the control output port 204 of the machine controller 202 is communicatively coupled to the input port 210 for the input signal of the inertial navigation system 208 to allow the position determination unit 209 to correct the position of the mining machine 200 based on the machine control signal 206. Communicatively coupled encompasses a wide range of different couplings that allow communication, such as digital and analog data as well as other signals, to be transmitted over the coupling. Examples of communicatively coupled include galvanic connection of metal, such as copper, wires, fibre optic cables, galvanically decoupled but optically coupled, such as using opto-couplers. This includes bus systems including CAN and I2C, or wirelessly coupled, such as using Wifi, 3G, LTE or other wireless communication technologies including radio frequency and infrared communication as well as coupled over audio waves.

[40] While some examples herein relate to a continuous miner, the same systems and methods may be applicable for other mining machines, such as haulers and shovels as well as other machinery, such as tunnel boring machines or agricultural machines.

[41] The machine controller 202 may be a receiver of machine control signals from a remote control. For example, an operator may observe the continuous miner 200 from a safe distance and control the continuous miner 200 using a hand-held remote
control. The machine controller 202 receives the commands from the remote control and translates them into machine control signals.

[42] In other examples, the machine controller 202 is an autonomous controller that generates machine control signals in response to sensor inputs and following the desired layout of the underground mine 100.

[43] Fig. 2b illustrates the control flow of continuous miner 200. Positioning system 209 determines control signals 224 at the output of the positioning system 209 based on the determined position. At the input, positioning system 209 receives control signals 206 that control the machine 200, such as a brake signal, from machine control 202.

[44] As can be seen when comparing the control flow in Fig. 2b to the control flow of the prior art in Fig. 1b, the control signals 206 in Fig. 2a are at the input of the positioning system 209 while the control signals 154 in Fig. 1b are only an output of the positioning system 152. Instead of the control signals 206 at the input in Fig. 2a, there are sensor signals 158 at the input of the positioning system 152 in Fig. 1b.

[45] Figs. 3a to 3c illustrate a work cycle of the continuous miner 200. In Fig. 3a, the continuous miner advances into an existing room towards the seam 102. When the continuous miner 200 is about to reach the end of the room, machine controller 202 activates the cutting drum 216 such as by powering an electric motor that rotates the cutting drum 216. While the cutting drum 216 rotates the continuous miner advances further as indicated by arrow 302 and into the seam 102 arriving at the position illustrated in Fig. 3b.

[46] At this stage, the machine controller 202 deactivates the propulsion system 212 and activates the braking system 214, which stops the advancement of the continuous miner 200. More particularly, machine controller 202 generates machine control signal 206 that deactivates the propulsion system 212 and activates the braking system 214. Machine controller 202 then activates actuators of the boom 218, such as
hydraulic jacks to lower the boom 218 as indicated by arrow 312. As the cutting drum 216 is lowered, the cutting drum 216 vertically extracts the coal from the seam 102 until the cutting drum arrives at the floor of the room arriving at the position illustrated in Fig. 3c. At this stage, the machine controller 202 may activate the actuators of boom 218 to lift the cutting drum 216 as indicated by arrow 322. Machine controller 202 then de-activates the braking system 214 and activates propulsion system 212 to advance the continuous miner 200 as shown in Fig. 3a.

[47] Figs. 3a to 3c show that during each cycle of the continuous miner 200 there is a period where the continuous miner is stationary, which is the period illustrated in Fig. 3b. This period can be used for correcting the position determined by the INS 208 by employing a zero velocity updating routine. In other examples, continuous miner 200 may also stop for roof bolting, that is, the machine controller 202 activates the braking system 214 while a roof bolting machine (not shown) drives bolts into the mine roof to prevent a collapse of the mine roof onto the continuous miner 200. When the roof bolting machine is finished, the machine controller 202 deactivates the braking system 214 and continues the mining cycle. As the continuous miner 200 is stationary during roof bolting, this period of time as detected by observing the machine control signal 206 can also be used for zero velocity updating.

[48] The continuous miner 200 may have sensors to measure a machine state, such as activation of electric motors driving the propulsion system 212 or odometers measuring the speed or rotation of the propulsion system 212. Each of these sensors comprises a sensor output for a sensor output signal. However, the sensor output signal of each of the one or more sensors is isolated from the input port 210 of the inertial navigation system 208, such as by electrically insulating signal wires from each other or by logically isolating data messages by disregarding data packets on a bus system as described further below. As a result, the INS 208 does not need to detect periods of movement based on the sensor signals, such as an odometer signal.

[49] Instead, INS 208 receives the machine control signal 206 from machine controller 202 and can activate the zero velocity update based on the machine control
signal 206. For example, machine controller 202 activates the braking system 214 by setting a brake activation flag on the machine control signal 206. The INS 208 receives the brake activation flag and in response, the INS 208 can activate the zero velocity update. In another example, the INS 208 listens to the electric motor control data on the machine control signal 206 and activates the zero velocity update if the electric motor control data indicates deactivation of the motors driving the propulsion system 212. In yet another example, the machine control signal 206 may comprise an ignition circuit breaker signal connected to an internal combustion engine and the INS 208 activates the zero velocity update if the circuit breaker signal indicates that ignition is disabled.

[50] In one example, the INS 208 uses the machine control signal 206 to indicate that the continuous miner 200 is potentially stationary. For example, if the braking system 214 is activated to stop the continuous miner 200, the INS 208 allows zero velocity updating but may not activate it if a further condition is not met. For example, INS 208 comprises a motion sensor and only activates the zero velocity update if the motion sensor detects no motion as well as the braking system 214 is activated. In other words, the de-activation of the braking system 214 inhibits zero velocity updates but the activation of the braking system 214 allows the zero velocity update to be applied or not to be applied depending on the motion sensor output, for example.

[51] In one example, the INS 208 is a device by Northrop Grumman with model number LN-270. INS 208 may comprise a fibre optic gyroscope (FOG) and a MEMS accelerometer to provide measurements of the body frame angular velocity and acceleration along three orthogonal axes. The FOG may employ the Sagnac effect. That is, an optical signal is coupled into a looped fibre optic coil at both ends. When the fibre optic coil rotates, the speed of light at which the optical signal travels through the loop remains constant while the loop rotates. This results in a change of the interference pattern of both signals depending on the rotational speed.

[52] The motion sensor may be a micro electro-mechanical systems (MEMS) accelerometer that may comprise a cantilever beam with a proof mass. Damping may
result from residual gas sealed in the device. Under the influence of external accelerations the proof mass deflects from its neutral position. This deflection is measured in an analog or digital manner. For example, the capacitance between a set of fixed beams and a set of beams attached to the proof mass is measured. Another example uses integrated piezoresistors in the springs to detect spring deformation, and thus deflection.

[53] A processor integrates the quantities provided by the FOG and accelerometer to produce a solution of the position, velocity and attitude of the body in a reference frame of interest. The processor corrects the result by employing zero velocity updating, such as by applying a Kalman filter as described in: Paul D. Groves, “Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems”, second edition, Artech House, 1 Apr 2013 and in particular section 15.3 “Zero Updates” from page 638.

[54] In one example, the processor can repeatedly correct the navigation solution according to the following equations from Kalman Filtering theory:

[55] Predicted (a priori) state estimate: \( \mathbf{x}_{k|k-1} = \mathbf{A}_k \mathbf{x}_{k-1|k-1} + \mathbf{B}_k \mathbf{u}_k \)

Predicted (a priori) estimate covariance \( \mathbf{P}_{k|k-1} = \mathbf{A}_k \mathbf{P}_{k-1|k-1} \mathbf{A}_k^T + \mathbf{Q}_k \)

Measurement residual: \( \mathbf{y}_k = \mathbf{z}_k - \mathbf{H}_k \mathbf{x}_{k|k-1} \)

Innovation (or residual) covariance \( \mathbf{S}_k = \mathbf{H}_k \mathbf{P}_{k|k-1} \mathbf{H}_k^T + \mathbf{R}_k \)

Optimal Kalman gain \( \mathbf{K}_k = \mathbf{P}_{k|k-1} \mathbf{H}_k^T \mathbf{S}_k^{-1} \)

Updated (a posteriori) state estimate \( \mathbf{x}_{k|k} = \mathbf{x}_{k|k-1} + \mathbf{K}_k \mathbf{y}_k \)

Updated (a posteriori) estimate covariance \( \mathbf{P}_{k|k} = (I - \mathbf{K}_k \mathbf{H}_k) \mathbf{P}_{k|k-1} \).

[56] The processor repeats the above calculations to iteratively update the navigation solution of the continuous miner 200. In one example, the values of the above matrices are determined based on library functions providing the Kalman filter, such as Python libraries pykalman, scipy, filterpy or Matlab kalman class in the Control System Toolbox.
Fig. 4 illustrates an example, where the machine control signal 206 is implemented in the form of a signal bus 402, such as a CAN bus. The signal bus 402 is electrically coupled to the control output port 204 and the input port 210 to transmit the machine control signal. Of course, if the braking system 214 is to be controlled, the signal bus 402 is also electrically coupled to the braking system 214. The advantage of using a bus system is that the input port 210 of the INS 208 can be easily connected to the signal bus 402 without requiring any modification of the existing configuration of the electrical system of the continuous miner 200. Since the INS 208 does not need to send data over the CAN bus 402 it is sufficient to implement a bus sniffer into INS 208 to detect a particular identifier, such as a binary identifier for ‘Brake_1’ and a binary data value representing activation of the braking system 214.

Fig. 5 illustrates the structure of the INS 208 in more detail. As described above, the INS 208 comprises an input port 210 that may be connected to a signal bus 402 transmitting a machine control signal, such as a CAN bus signal comprising address and data bits. INS 208 further comprises a processor 502 corresponding to position determination unit 209 and connected to a program memory 504, such as flash ROM, and a data memory 506 such as a flash R/W memory. Processor 502 receives sensor data from inertial sensors 508, such as fibre optical gyroscopes and acceleration sensors and calculates a position update based on the current position and the sensor data.

Input port 210 is connected to a bus sniffer 510 that generates a binary ‘1’ at its output when the pre-defined data packet representing the machine control signal arrives on the bus, such as a break activation data packet. The bus sniffer 510 together with a motion sensor 512 are inputs to an AND gate 514. In this example, the motion sensor 512 generates a binary ‘0’ if no motion is detected, which is inverted before reaching the AND gate 514, such that binary ‘1’ indicates that zero velocity updating is possible depending on the signal from the bus sniffer 510. The output of AND gate 514 is ‘1’ only if both inputs are ‘1’, that is, only if the bus sniffer 510 detects the break activation packet and the motion sensor 512 detects no motion. The AND gate 514 is
connected to processor 502 such that a binary ‘1’ at the output of the AND gate triggers zero velocity updating of the INS position.

[60] In cases where the continuous miner 200 comprises an odometer, the odometer signal may also be transmitted over CAN bus 402. In this example, the bus sniffer 510 is considered to isolate the odometer signal from the INS 208 input port 210 by disregarding data packets originating from the odometer. This may be achieved by disregarding all packets with an ‘odometer_1’ identifier.

[61] The bus sniffer 510 and AND gate 514 may also be integrated into processor 502, such as by appropriate program code stored on program memory 504. In one example, processor 502 is a microcontroller comprising multiple A/D converters that can be directly coupled to the bus 402 and the converted digital signal can be used by software functions to detect the break activation packet.

[62] Fig. 6 illustrates a method 600 for determining a position of the continuous miner 200 as stored in the form of program code on non-transitory program memory 504 and as performed by processor 502. The method commences by determining 602 an initial position of the continuous miner 200. The initial position may be an initialisation position, such as a known absolute position of the continuous miner 200 or the position determined in a previous iteration of method 600.

[63] Processor 502 then determines 604 an updated position of the mining machine based on the initial position and based on data from one or more inertial sensors 508, such as by integrating sensor data to perform dead reckoning based on attitude and velocity. Processor 502 then performs zero velocity updating to determine 606 a corrected position of the mining machine. The determined corrected position is based on the machine control signal 206 on bus 402 that controls movement of the continuous miner 200.

[64] Fig. 6 is to be understood as a blueprint for the navigation program and may be implemented step-by-step, such that each step in Fig. 6 is represented by a function
or class in a programming language, such as C++ or Java. The resulting source code is then compiled and stored as computer executable instructions on program memory 504.

[65] While the above examples relate to zero velocity updating, the methods and systems described herein are equally applicable to performing vehicle motion sensor aiding more generally using the machine control signal 206 as an input. For example, machine controller 202 generates a control signal 206 indicative of the absolute speed of the electric motors driving the propulsion system 312, such as by writing a bus packet with address ‘motor_1’ and data ‘0010’ for speed setting ‘2’. Processor 502 receives this data packet and incorporates the speed setting into the correction of the updated position, such as by setting the correction variable of a Kalman filter to ‘2’.

[66] In the example of zero velocity updating processor 502 may determine whether the continuous miner 200 is stationary based on the machine control signal 216, such as by determining that the machine control signal 216 indicates that the continuous miner 200 is stationary and that a motion sensor 508 indicates that the continuous miner 200 is stationary. Processor 502 then performs the zero velocity update upon determining that the continuous miner 200 is stationary.

[67] The following description provides more detailed information on the INS system 208 comprising processor 502 connected to a program memory 504, a data memory 506, a communication port 210. The processor may also be referred to as position determination unit. The program memory 504 is a non-transitory computer readable medium, such as a hard drive, a solid state disk or CD-ROM. Software, that is, an executable program stored on program memory 504 causes the processor 502 to perform the method in Fig. 6, that is, processor 502 determines an initial position, an updated position based on sensor data from sensors 508 and a corrected position based on machine control signal 206 on bus 402. The term “determining a position” refers to calculating a value that is indicative of the position. This also applies to related terms.

[68] The processor 502 may then store any determined position on data store 506, such as on RAM or a processor register. Processor 502 may also send the determined
position via communication port 210 or a separate communication port, such as a Wifi adapter, to a server, such as mine control system.

[69] The processor 502 may receive data, such as the data CAN bus 402, from data memory 506 as well as from the communications port 210.

[70] In one example, the processor 502 receives and processes the machine control signal 206 in real time. This means that the processor 502 determines the positions every time a data packet related to the machine control signal 206 is received from bus 402 and completes this calculation before the bus 402 provides the next machine control signal data packet.

[71] Although communications port 210 is shown as distinct entities, it is to be understood that any kind of data port may be used to receive data, such as a network connection, a memory interface, a pin of the chip package of processor 502, or logical ports, such as IP sockets or parameters of functions stored on program memory 504 and executed by processor 502. These parameters may be stored on data memory 506 and may be handled by-value or by-reference, that is, as a pointer, in the source code.

[72] The processor 502 may receive data through all these interfaces, which includes memory access of volatile memory, such as cache or RAM, or non-volatile memory, such as an optical disk drive, hard disk drive, storage server or cloud storage.

[73] It is to be understood that any receiving step may be preceded by the processor 502 determining or computing the data that is later received. For example, the processor 502 determines machine control data and stores the machine control data in data memory 506, such as RAM or a processor register. The processor 502 then requests the data from the data memory 506, such as by providing a read signal together with a memory address. The data memory 506 provides the data as a voltage signal on a physical bit line and the processor 502 receives the machine control data via a memory interface.
Fig. 7 illustrates a computer system, such as a tablet computer including iPads, Android tablets, etc. for monitoring and controlling underground mine 100. Computer system 700 comprises a processor executing software installed on program memory. Computer system 700 receives the corrected position of the continuous miner and generates a graphical representation 702 of the underground mine 100. The graphical representation 702 comprises an icon 704 representing the continuous miner 200. The location of the icon 704 is based on the corrected position of the continuous miner 200 and is located relative to the mine representation 702 according to the corrected position. In other words, computer system 700 receives the data values indicative of the corrected position and transforms these data values to pixel values representing locations on the screen of the computer system 700.

Graphical representation 702 further comprises a mining plan 706 shown in dashed lines. Since the icon 704 is located accurately relative to the mine plan, an operator can easily control continuous miner 200 to realise the planned layout as indicated by mine plan 706. For example, computer system 700 may display an advance button 708 and a stop button 708. When an operator activates the advance button 708, the computer system 700 generates a control signal for the continuous miner 200, such that the continuous miner 200 advances into the seam 120 in a direction determined by the mine plan 706 and by automatically cycling through the stages in Figs. 3a to 3c. When the continuous miner 200 reaches an end point, the operator presses the stop button 708 to stop the continuous miner 200.

In order to achieve the correct vertical layout of the mine 100, the computer system 700 has stored the vertical dimensions of the seam 120 and generates signals to control the movement of the boom 218. For example, if the seam 120 slopes upwardly, the limits of the movement of the boom 218 are adjusted such that the maximum and the minimum height of the cutting drum 216 are adjusted upwardly. Since the position of the continuous miner 200 is corrected and therefore more accurate than with other existing systems, the position of the icon 704 is more accurate in relation to the mine plan 706. As a result, the mine plan 706 can be followed more accurately which results
in a more efficient and safe mining operation eventually leading to increased profitability.

[77] It is to be understood that throughout this disclosure unless stated otherwise, nodes, edges, graphs, solutions, variables, evacuation plans and the like refer to data structures, which are physically stored on data memory 506 or processed by processor 502. Further, for the sake of brevity when reference is made to particular variable names, such as “position” or “signal” this is to be understood to refer to values of variables stored as physical data in the INS system 208.

[78] It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the specific embodiments without departing from the scope as defined in the claims.

[79] It should be understood that the techniques of the present disclosure might be implemented using a variety of technologies. For example, the methods described herein may be implemented by a series of computer executable instructions residing on a suitable computer readable medium. Suitable computer readable media may include volatile (e.g. RAM) and/or non-volatile (e.g. ROM, disk) memory, carrier waves and transmission media. Exemplary carrier waves may take the form of electrical, electromagnetic or optical signals conveying digital data steams along a local network or a publically accessible network such as the internet.

[80] It should also be understood that, unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "estimating" or "processing" or "computing" or "calculating", "optimizing" or "determining" or "displaying" or "maximising" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that processes and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system.
memories or registers or other such information storage, transmission or display devices.

[81] The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.
CLAIMS:

1. A mining machine, the mining machine comprising:
   a machine controller comprising a control output port for a machine control signal that controls movement of the mining machine; and
   an inertial navigation system comprising
      a position determination unit determining a position of the mining machine, and
      an input port for an input signal indicative of the movement of the mining machine, the input port being communicatively coupled to the position determination unit,
   wherein the control output port of the machine controller is communicatively coupled to the input port for the input signal of the inertial navigation system to allow the position determination unit to calculate a corrected position of the mining machine based on the machine control signal that controls the movement of the mining machine.

2. The mining machine of claim 1, wherein the mining machine is a continuous miner.

3. The mining machine of claim 1 or 2, further comprising one or more sensors of a machine state, each sensor comprising a sensor output for a sensor output signal, wherein the sensor output signal of each of the one or more sensors is isolated from the input port for the input signal of the inertial navigation system.

4. The mining machine of claim 3, wherein the one or more sensors of a machine state comprise an odometer and the sensor output signal of the odometer is isolated from the input signal of the inertial navigation system.

5. The mining machine of any one of the preceding claims, wherein the machine control signal comprises a braking signal that activates a brake of the mining machine, the braking signal being communicatively coupled to the brake and to the input port for the input signal of the inertial navigation system to allow the position determination
unit to calculate a corrected position of the mining machine based on the braking signal when the braking signal activates the brake of the mining machine.

6. The mining machine of any one of the preceding claims, wherein the machine control signal comprises a motor control signal that provides commands to a motor of the mining machine, the motor control signal being communicatively coupled to the motor and to the input port for the input signal of the inertial navigation system to allow the position determination unit to calculate a corrected position of the mining machine based on the motor control signal when the motor control signal provides commands to the motor of the mining machine.

7. The mining machine of claim 6, wherein the motor control signal comprises an ignition circuit breaker signal that breaks an ignition circuit of the mining machine or an electric motor control signal that provides commands to an electric motor, the ignition circuit breaker signal or electric motor control signal being communicatively coupled to the ignition circuit breaker or to the electric motor, respectively, and to the input port for the input signal of the inertial navigation system to allow the position determination unit to calculate a corrected position of the mining machine based on the ignition circuit breaker signal or the electric motor control signal when the ignition circuit breaker signal breaks an ignition circuit of the mining machine or when the electric motor control signal provides commands to the electric motor.

8. The mining machine of any one of the preceding claims, further comprising a signal bus electrically coupled to the control output port and the input port to transmit the machine control signal to the input port for the input signal of the inertial navigation system to allow the position determination unit to calculate the corrected position of the mining machine based on the machine control signal that is transmitted on the signal bus and controls the movement of the mining machine.

9. The mining machine of any one of the preceding claims, wherein the inertial navigation system comprises a motion sensor to set the inertial navigation system to a
moving state while the machine control signal indicates to the inertial navigation system that the mining machine is desired to be stationary.

10. The mining machine of any one of the preceding claims, wherein the inertial navigation system comprises a motion sensor and a logical AND module to set the inertial navigation system to a stationary state where the zero velocity update is performed when both the machine control signal that controls the movement of the mining machine and the motion sensor indicate the mining machine is stationary.

11. The mining machine of any one of the preceding claims, wherein the inertial navigation system comprises a fiber-optic gyroscope.

12. A method for determining a position of a mining machine, the method comprising:
   - determining an initial position of the mining machine;
   - determining an updated position of the mining machine based on the initial position and based on data from one or more inertial sensors; and
   - determining a corrected position of the mining machine,
wherein determining the corrected position is based on a machine control signal that controls movement of the mining machine.

13. The method of claim 12, wherein determining the corrected position comprises performing vehicle motion sensor aiding.

14. The method of claim 13, wherein the machine control signal is indicative of a desired velocity of the mining machine and performing vehicle motion sensor aiding comprises determining the corrected position based on the desired velocity of the mining machine as indicated by the machine control signal.

15. The method of claim 13 or 14, wherein performing vehicle motion sensor aiding comprises performing zero velocity updating.
16. The method of claim 15, wherein performing zero velocity updating comprises determining whether the mining machine is stationary based on the machine control signal and performing the zero velocity update upon determining that the mining machine is stationary.

17. The method of claim 16, wherein determining that the mining machine is stationary comprises determining that the machine control signal indicates that the mining machine is stationary and that a motion sensor indicates that the mining machine is stationary.

18. Software that, when installed on a computer, causes the computer to perform the method of any one of claims 12 to 17.
determining an initial position

determining an updated position

determining a corrected position

Fig. 6

Fig. 7