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AUXILIARY WIRELESS DEVICE FOR POWER TOOL

Abstract

Certain embodiments provide an auxiliary wireless device for a power tool that includes a body, a wireless communication unit (WCU), an inertial measurement unit (IMU), and a controller. The body is removably attachable to a housing of a power tool. The WCU includes a wireless transceiver. The IMU is configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data. The controller is configured to determine a loaded operational time of the power tool over a time period based on the IMU sensor data, determine a cumulative loaded operational time of the power tool over a cumulative time period based on loaded operational times for a number of time periods, and send the cumulative loaded operational time to the WCU for transmission to a remote device. The power tool is activated in a loaded condition during the loaded operational time.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application claims the benefit of U.S. Provisional Application Ser. No. 63/552,654 (filed on Feb. 12, 2024), the contents of which is incorporated herein by reference in its entirety.

INTRODUCTION
[0002] The present disclosure relates to power tools, and particularly to an auxiliary wireless device for a power tool.
SUMMARY
[0003] According to an embodiment of the invention, an auxiliary wireless device for a power tool is provided that includes a body, a wireless communication unit (WCU), an inertial measurement unit (IMU), and a controller in communication with the WCU and the IMU. The body is removably attachable to a housing of a power tool. The WCU is supported by the body, and includes a wireless transceiver. The IMU is supported by the body, and is configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data. The controller is configured to determine a loaded operational time of the power tool over a time period based on the IMU sensor data, determine a cumulative loaded operational time of the power tool over a cumulative time period based on loaded operational times for a number of time periods, and send the cumulative loaded operational time to the WCU for transmission to a remote device. The power tool is activated in a loaded condition during the loaded operational time.
[0004] According to another embodiment of the invention, an auxiliary wireless device for a power tool is provided that includes a body, a wireless communication unit (WCU), an inertial measurement unit (IMU), and a controller in communication with the WCU and the IMU. The body is removably attachable to a housing of a power tool. The WCU is supported by the body, and includes a wireless transceiver. The IMU is supported by the body, and is configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data. The controller is configured to execute a machine learning (ML) model to determine a cumulative loaded operational time of the power tool over a cumulative time period based on loaded operational times for a number of time periods, and send the cumulative loaded operational time to the WCU for transmission to a remote device. The power tool is activated in a loaded condition during the loaded operational time.
[0005] According to another embodiment of the invention, an auxiliary wireless device for a power tool is provided that includes a body, a wireless communication unit (WCU), an inertial measurement unit (IMU), and a controller in communication with the WCU and the IMU. The body is removably attachable to a housing of a power tool. The WCU is supported by the body, and includes a wireless transceiver. The IMU is supported by the body, and is configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data. The controller is configured to determine, based on the IMU sensor data over a time period, an operation parameter of the power tool, the operation parameter including at least one of a type of power tool, a type of operation being performed by the power tool, and a type of accessory mounted to the power tool, and send the operation parameter to the WCU for transmission to a remote device.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** depicts a perspective view of an example power tool with an example auxiliary wireless device, in accordance with embodiments of the present disclosure.

[0007] FIG. **2** depicts a perspective view of another example power with the example auxiliary wireless device, in accordance with embodiments of the present disclosure.

[0008] FIG. **3**A depicts a perspective view of a further example power tool with the auxiliary wireless device, in accordance with embodiments of the present disclosure.

[0009] FIGS. **3**B and **3**C depict side views of the example power tool depicted in FIG. **3**A in a first position and a second position (respectively), in accordance with embodiments of the present disclosure.

[0010] FIG. **4** depicts an example system for monitoring power tools, in accordance with embodiments of the present disclosure.

[0011] FIGS. **5**A to **5**F depict inertial measurement unit (IMU) sensor data plots for the example power tool depicted in FIG. **1**, in accordance with embodiments of the present disclosure.

[0012] FIGS. **6**A to **6**J depict IMU sensor data plots for the example power tool depicted in FIG. **2**, in accordance with embodiments of the present disclosure.

[0013] FIGS. **7**A to **7**G depict IMU sensor data plots for the example power tool depicted in FIG. **3**, in accordance with embodiments of the present disclosure.

[0014] FIGS. **8**A to **8**D depict flow charts illustrating rules-based functionality associated with the example auxiliary wireless device for determining power tool operational information, in accordance with embodiments of the present disclosure.

[0015] FIGS. **9**A to **9**D depict flow charts illustrating ML-based functionality associated with the example auxiliary wireless device for determining power tool operational information, in accordance with embodiments of the present disclosure.

[0016] FIG. **9**E depicts a flow chart illustrating functionality associated with training an ML model to predict power tool operational states or other information, in accordance with embodiments of the present disclosure.

[0017] FIG. **10** depicts a flow chart illustrating functionality associated with the example auxiliary wireless device for determining power tool operational parameters, in accordance with embodiments of the present disclosure.

[0018] FIG. **11** depicts a flow chart illustrating functionality associated with determining a type of tool, in accordance with embodiments of the present disclosure.

[0019] FIG. **12** depicts a flow chart illustrating functionality associated with determining a type of accessory, in accordance with embodiments of the present disclosure.

[0020] FIG. **13** depicts a flow chart illustrating functionality associated with determining a type of fault, in accordance with embodiments of the present disclosure.

[0021] FIG. **14** depicts an IMU sensor data plot capturing mounting the example auxiliary wireless device in a power tool, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0022] The following description illustrates the claimed invention by way of example and not by way of limitation. The description clearly enables one skilled in the art to make and use the disclosure, describes several embodiments, adaptations, variations, alternatives, and uses of the disclosure, including what is presently believed to be the best mode of carrying out the claimed invention. Additionally, it is to be understood that the disclosure is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. The disclosure is capable of other embodiments and of being practiced or being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

[0023] Embodiments of the present disclosure advantageously provide an auxiliary wireless device for a power tool. The auxiliary device includes, inter alia, a controller, an inertial measurement unit (IMU), and a wireless communication unit (WCU). The controller is configured to determine, inter alia, power tool information associated with the power tool, such as an operational state, an operational time, and a cumulative operational time of the power tool based on IMU sensor data. In certain embodiments, the power tool information may also include one or more operational parameters of the power tool, such as the type of power tool, the type of operation being performed by the power tool, the type of accessory mounted to the power tool, etc.
[0024] In certain embodiments, the IMU sensor data may include 3-axis acceleration data and/or 3-axis angular rate data that are acquired when the power tool is operating in various operational states, such as activated in a loaded condition (or a loaded operational state), activated in an unloaded condition (or an unloaded operational state), not activated while the power tool is moving (or a non-operating movement state), and not activated while the power tool is not moving (or a rest state).
[0025] The power tool may be any type of cordless or corded, handheld or stationary power tool, including but not limited to, drill/drivers, hammer drills, impact drivers, wrenches, die grinders, straight grinders, polishers, routers, planers, circular saws, reciprocating saws, rotary hammers, etc. The type of operation being performed by the power tool may include drilling, driving, impact driving, heavy grinding, light grinding, polishing, removing material, cutting, etc. The type of accessory mounted to the power tool may include a drill bit, a driver bit, a socket, a grinding wheel, a cutting wheel, a circular saw blade, etc.
[0026] FIG. **1** depicts a perspective view of an example power tool with an auxiliary wireless device, in accordance with embodiments of the present disclosure.
[0027] In the embodiment depicted in FIG. **1**, power tool **100** is a cordless impact wrench. Power tool **100** may include, inter alia, removable battery pack **108**, housing **110**, transmission assembly **118** mounted to housing **110**, and auxiliary wireless device **150** mounted to housing **110**.
[0028] Housing **110** forms handle portion **112**, battery receptacle **114**, and motor case **116**. Handle portion **112** includes trigger **111**. Battery receptacle **114** is formed on the lower end of handle portion **112**, and motor case **116** is formed on the upper end of handle portion **112**.
[0029] Trigger **111** is configured to activate and deactivate power tool **100** in cooperation with control electronics (such as controller **120** depicted in FIG. **4**) which controls the supply of electric power from battery pack **108** to the electric motor (high speed, not visible) housed in motor case **116**.
[0030] Battery receptacle **114** is configured to removably receive battery pack **108**, such as a 20V max lithium-ion power tool battery pack, etc. Battery receptacle **114** may include two side walls (side wall **115** is depicted in FIG. **1**), and each side wall includes a lower rail that is configured to engage an upper channel of battery pack **108**. More particularly, the lower rails of the side walls are configured to slidingly engage with, and guide, the upper channels of battery pack **108** into a locked position with power tool **100**. Battery pack **108** may be unlocked and removed from battery receptacle **114** (or remain in the locked position) as needed for recharging.
[0031] Side wall **115** also includes cooling air slots **113** and threaded opening **117**. Cooling air slots **113** are configured to receive incoming cooling air into housing **110**. In certain embodiments, threaded opening **117** may be disposed within a raised portion of side wall **115** (as depicted in FIG. **1**).
[0032] Transmission assembly **118** is mounted on housing **110** forward of motor case **116**, and includes, inter alia, a planetary gear set (not visible) coupled to the drive shaft of the electric motor, an impactor assembly (not visible) coupled to the planetary gear set, and anvil assembly **119** coupled to the impactor assembly. Anvil assembly **119** is the output shaft for power tool **100**, which rotates about output shaft axis **104** when trigger **111** is activated.
[0033] The impactor assembly initially provides a continuous torque (via continuous rotation) to

anvil assembly **119** and the load until a torque threshold is reached, and then provides a dynamic torque (via periodic rotational impacts) to anvil assembly **119** and the load when a higher torque is required. In certain embodiments, the impactor assembly may include a spring-loaded, cam-operated hammer that cooperates with anvil assembly **119** to deliver the continuous torque or the dynamic torque to the load. The hammer includes a hammer body with two or more hammer heads, and anvil assembly **119** includes an anvil body with two or more anvil dogs. The hammer body surrounds the anvil body, and the hammer heads and the anvil dogs are configured to engage to provide continuous torque, and to periodically engage and disengage to provide dynamic torque.

[0034] When trigger **111** is deactivated, a pre-compressed coil spring forces the hammer heads to engage the anvil dogs. When trigger **111** is initially activated, the hammer heads remain engaged to the anvil dogs, and anvil assembly **119** continuously rotates about output shaft axis **104** until the torque threshold is reached. The hammer body then follows the cam path and moves away from the anvil body, which further compresses the coil-spring and disengages the hammer heads from the anvil dogs. After the hammer heads are fully disengaged from the anvil dogs, the coil spring forces the hammer body to accelerate and move along the cam path toward the anvil body, which causes the hammer heads to impact the anvil dogs, thereby providing a dynamic torque to the load. The properties of the spring (such as spring rate or stiffness, etc.), the cam path, the mass of the hammer, the number of heads on the hammer body, the number of dogs on the anvil body, etc., determine the dynamic torque that is applied.

[0035] Output accessory **102**, such as an impact socket, a deep impact socket, etc., may be removably attached to anvil assembly **119**.

[0036] Auxiliary housing **140** and auxiliary wireless device **150** are depicted in an exploded perspective view and a mounted perspective view in FIG. **1**.

[0037] Auxiliary housing **140** defines a cavity configured to receive auxiliary wireless device **150**, and includes a through-hole and two screw bosses. Auxiliary housing **140** is mounted to side wall **115** of battery receptacle **114** by aligning fastener **142** in the through-hole and then securing fastener **142** into threaded opening **117**. Other configurations of auxiliary housing **140**, mounting locations, and fasteners are also supported.

[0038] Auxiliary wireless device **150** includes body **152** with front surface **156**, an upper surface, a lower surface (not visible), a rear surface (not visible), and projection **155** extending from front surface **156** and the upper surface. Generally, body **152** houses a circuit board containing various electronic components, as discussed below with respect to FIG. **4**. The lower surface removably receives energy storage unit **154**, such as a coin cell battery, etc., and front surface **156** includes through-holes **158** that are configured to receive fasteners **159** for securing auxiliary wireless device **150** to auxiliary housing **140**. Projection **155** includes LED indicator light **157** that may indicate, inter alia, when data is being acquired, when data is being transmitted, etc.

[0039] Auxiliary wireless device **150** is mounted within auxiliary housing **140** by aligning fasteners **159** in through-holes **158** and securing fasteners **159** into the screw bosses of auxiliary housing **140**.

[0040] FIG. **2** depicts a perspective view of an example power tool with an auxiliary wireless device, in accordance with embodiments of the present disclosure.

[0041] In the embodiment depicted in FIG. **2**, power tool **200** is a cordless angle grinder. Power tool **200** may include, inter alia, removable battery pack **208**, housing **210**, gearcase assembly **218** mounted to housing **210**, and auxiliary wireless device **150** mounted within housing **210**. Side handle **230** may be attached to a left side mount on gearcase assembly **218** (as depicted in FIG. **2**) or a right side mount on gearcase assembly **218**.

[0042] Housing **210** forms handle portion **212**, battery receptacle **214**, and motor case **216**. Handle portion **212** includes paddle trigger **211**. Battery receptacle **214** is formed on the lower end of handle portion **212**, and motor case **216** is formed on the upper end of handle portion **212**.

[0043] Paddle trigger **211** is configured to activate and deactivate power tool **200** in cooperation with control electronics (such as controller **120** depicted in FIG. **4**) which controls the supply of electric power from battery pack **208** to the electric motor (high speed, not visible) housed in motor case **216**.

[0044] Battery receptacle **214** is configured to removably receive battery pack **208**, such as a 20V max lithium-ion power tool battery pack, etc. Battery receptacle **214** may include two side walls (side wall **215** is depicted in FIG. **2**), and each side wall includes a lower rail that is configured to engage an upper channel of battery pack **208**. More particularly, the lower rails of the side walls are configured to slidingly engage with, and guide, the upper channels of battery pack **208** into a locked position with power tool **200**. Battery pack **208** may be unlocked and removed from battery receptacle **214** (or remain in the locked position) as needed for recharging.

[0045] Side wall **215** also includes cooling air slots **213** and threaded opening **217**. Cooling air slots **213** are configured to receive incoming cooling air into housing **210**. In certain embodiments, threaded opening **217** may be disposed within a raised portion of side wall **215** (as depicted in FIG. **2**).

[0046] Gearcase assembly **218** is mounted on housing **210** forward of motor case **216**, and includes, inter alia, a bevel gear (not visible) coupled to a pinion (bevel gear) on the drive shaft of the electric motor, and to output shaft **219**. Output shaft **219** rotates about output shaft axis **204** when paddle trigger **211** is activated.

[0047] Output accessory **202**, such as a grinding wheel, a cutting wheel, a polishing wheel, etc., may be removably attached to output shaft **219** using a clamp washer and flanged hex nut.

[0048] Auxiliary wireless device **150** is depicted in a mounted perspective view in FIG. **2**.

[0049] In certain embodiments, auxiliary wireless device **150** may be mounted within pocket **240** of housing **210**. Similar to auxiliary housing **140**, pocket **240** defines a cavity configured to receive auxiliary wireless device **150**, and includes two screw bosses or threaded openings. Auxiliary wireless device **150** is mounted within pocket **240** by securing fasteners **159** into the screw bosses or threaded openings of pocket **240**. Other configurations of pocket **240**, mounting locations, and fasteners are also supported. In other embodiments, auxiliary housing **140** may be mounted to side wall **215**, as described above with respect to side wall **115**, and auxiliary wireless device **150** may be mounted within auxiliary housing **140**.

[0050] FIG. **3**A depicts a perspective view of a further example power tool with an auxiliary wireless device, in accordance with embodiments of the present disclosure.

[0051] In the embodiment depicted in FIG. **3**A, power tool **300** is a cordless miter saw. Power tool **300** may include, inter alia, miter saw **370** rotationally coupled to adjustable base **380** using counterbalanced hinge **372**. Miter saw **370** includes, inter alia, removable battery pack **308**, housing **310**, movable blade guard **313**, gearcase assembly **318** mounted to housing **310**, and auxiliary wireless device **150** mounted within a pocket of housing **310** (such as pocket **240**), within an auxiliary housing mounted to housing **310** (such as auxiliary housing **140**). Other mounting configurations for auxiliary wireless device **150** are also supported.

[0052] Housing **310** forms handle portion **312**, battery receptacle **314**, and motor case **316**. Handle portion **312** includes trigger **311**. Battery receptacle **314** is formed on the lower end of handle portion **312**, and motor case **316** is formed above battery receptacle **314**.

[0053] Trigger **311** is configured to activate and deactivate power tool **300** in cooperation with control electronics (such as controller **120** depicted in FIG. **4**) which controls the supply of electric power from battery pack **308** to the electric motor (high speed, not visible) housed in motor case **316**.

[0054] Battery receptacle **314** is configured to removably receive battery pack **308**, such as a 20V max lithium-ion power tool battery pack, etc. Battery receptacle **314** may include two side walls, and each side wall includes a lower rail that is configured to engage an upper channel of battery pack **308**. More particularly, the lower rails of the side walls are configured to slidingly engage with, and guide, the upper channels of battery pack **308** into a locked position with power tool **300**.

Battery pack **308** may be unlocked and removed from battery receptacle **314** (or remain in the locked position) as needed for recharging.

[0055] The side walls also include cooling air slots and threaded openings. The cooling air slots are configured to receive incoming cooling air into housing **310**. In certain embodiments, the threaded openings may be disposed within raised portions of the side walls.

[0056] Gearcase assembly **318** is mounted on housing **310** forward of motor case **316**, and includes, inter alia, a bevel gear set (not visible) coupled to the drive shaft of the electric motor, and to a spindle (output shaft, not visible). The output shaft rotates about output shaft axis **304** when trigger **311** is activated.

[0057] Output accessory **302**, such as a cutting blade, etc., may be removably attached to the output shaft using a clamp washer and a blade screw.

[0058] Auxiliary wireless device **150** is depicted in an unmounted perspective view in FIG. **3**A.

[0059] Miter saw **370** rotates about pivot axis **374** from a first position (FIGS. **3**A, **3**B) to a second position (FIG. **3**C). Movable blade guard **313** moves up as the operator pulls handle portion **312** down to move miter saw **370** from the first position to the second position to engage a workpiece placed on table **382** and against fence **384** of adjustable base **380**. Similarly, movable blade guard **313** moves up as the operator pulls handle portion **312** up to move miter saw **370** from the second position to the first position to disengage from the workpiece.

[0060] FIGS. **3**B and **3**C depict right side views of the example power tool depicted in FIG. **3**A in the first position and the second position (respectively), in accordance with embodiments of the present disclosure.

[0061] Miter saw **370** and adjustable base **380**, as well as output accessory (blade) **302**, battery pack **308**, handle portion **312**, movable blade guard **313** are identified.

[0062] It should be understood that while power tools **100**, **200**, **300** are described by way of examples, the teachings of this disclosure are not limited to cordless impact wrenches, angle grinders, and miter saws. Rather, power tools **100**, **200**, **300** may be any type of cordless or corded, handheld or stationary power tool, including but not limited to, drill/drivers, hammer drills, impact drivers, wrenches, die grinders, straight grinders, polishers, routers, planers, circular saws, reciprocating saws, rotary hammers, etc. Further, while the embodiments above describe the wireless auxiliary device **150** being a discrete chip module that is removably mounted into a pocket of the power tool housing, other configurations and mounting locations of the wireless auxiliary device **150** are within the scope of this disclosure. For example, the wireless auxiliary device **150** may be configured as, or incorporated into, a tag device mountable on an outer surface of the housing of the power tool via an adhesive or fasteners. An example of such a tag device includes, but is not limited to, the DeWalt® DCE041 Tool Connect™ Tag. In another example, the wireless auxiliary device **150** may be mountable onto an accessory of the power tool (e.g., the side handle **230** or blade guard **313**), or integrally incorporated inside the accessory of the power tool (e.g., inside the cylindrical housing of the side handle **230**). In another example, the wireless auxiliary device **150** may be mounted discretely on an outer surface of the battery pack **108**, **208**, **308**, or provided integrally and internally within the battery pack **108**, **208**, **308**. This configuration may enable the electronics and control circuitry of the battery pack to have access to the IMU sensor data of the wireless auxiliary device **150**.

[0063] FIG. **4** depicts an example system for monitoring power tools, in accordance with embodiments of the present disclosure.

[0064] System **405** includes, inter alia, one or more power tools **400** (such as power tools **100**, **200**, **300**), network(s) **410**, tool monitoring device(s) **420** coupled to network **410**, and tool monitoring system **430** coupled to network **410**. In certain embodiments, system **405** also includes model training system **440** coupled to network **410**.

[0065] Each power tool **400** includes an auxiliary wireless device **150** mounted within a pocket of the power tool housing (such as pocket **240**) or within an auxiliary housing that is mounted to the power tool housing (such as auxiliary housing **140**). As noted above, other mounting configurations for auxiliary wireless device **150** are also supported.

[0066] Each power tool **400** includes control electronics, such as controller **120** and memory **122**. Controller **120** may be a microcontroller, a microprocessor, an application integrated circuit (ASIC), a field-programmable gate array (FPGA), etc. In certain embodiments, the control electronics may include one or more communications units, such as wireless communications unit (WCU) **124**, serial communications unit (SCU) **126**, etc.

[0067] WCU **124** may include a Bluetooth/Bluetooth Low Energy (BLE) integrated circuit (IC), module, system-on-chip (SoC), etc. that includes a processor, memory, a Bluetooth transceiver, etc., a WiFi module, etc. WCU **124** may be configured to be coupled to network **410**, and in certain embodiments, WCU **124** may be configured to be directly coupled to auxiliary wireless device **150** (dashed line in FIG. **4**). In certain embodiments, WCU **124** may receive information from auxiliary wireless device **150** via the advertising signals broadcast from WCU **164**. In other words, a two-way communication link does not need to be established between WCU **124** and WCU **164** to receive data. SCU **126** may include a universal serial bus (USB) module, an RS-232 module, etc., and, in certain embodiments, SCU **126** may be configured to be directly coupled to auxiliary wireless device **150** when mounted within the power tool housing (dashed line in FIG. **4**).

[0068] Auxiliary wireless device **150** includes, inter alia, controller **160** (such as a microcontroller, a microprocessor, etc.), memory **162**, wireless communication unit (WCU) **164**, inertial measurement unit (IMU) **168**, and communications bus **169**. In certain embodiments, controller **160**, memory **162**, and IMU **168** may be combined into a single module or SoC.

[0069] In certain embodiments, auxiliary wireless device **150** may also include audible vibration detector **161** (such as a microphone). Audible vibration data acquired by the audible vibration detector **161** (e.g., associated with a tool operation) can be processed along with the IMU data to detect the tool's operating cycles and conditions, tool type, abrasive type, operation type, etc. For example, the sound from a grinder cutting operation is different than the sound from a grinding operation. In certain embodiments, the audible vibration data may be processed in the time domain, and at least a portion of the audible time domain data may be compared to known audible time domain signatures to detect known events or aspects about a tool, such as the tool's operating cycles and conditions, tool type, abrasive type, operation type, etc. In certain other embodiments, the audible vibration data may be converted to the frequency domain, and the audible frequency domain data may be compared to known audible frequency domain signatures to detect known events or aspects about a tool, such as the tool's operating cycles and conditions, tool type, abrasive type, operation type, etc.

[0070] IMU **168** may include, inter alia, a 3-axis digital accelerometer, a 3-axis digital gyroscope, a microcontroller or microprocessor, a communications interface (I/F), etc. The 3-axis digital accelerometer measures linear acceleration in units of g (or mg) in three orthogonal axes, i.e., a 1.sup.st axis (such as an X-axis), a 2.sup.nd axis (such as a Y-axis), and a 3.sup.rd axis (such as a Z-axis). The linear acceleration measurement range may be ± 1 g, ± 2 g, . . . , ± 10 g, and so on. Similarly, the 3-axis digital gyroscope measures angular rate in units of degrees per second (degrees/sec) (or millidegrees per second, mdps) in the same three orthogonal axes. The angular rate measurement range may be ± 100 dps, ± 200 dps, . . . , ± 1000 dps, etc.

[0071] Generally, IMU **168** outputs IMU sensor data, including at least one of the 3-axis acceleration data and the 3-axis angular rate data, at a particular output data rate, such as 100 Hz, 200 Hz, 400 Hz, 800 Hz, 1600 Hz, etc. In certain embodiments, IMU **168** outputs IMU sensor data that includes both 3-axis acceleration data and 3-axis angular rate data, while in other embodiments, IMU **168** outputs IMU sensor data that includes either 3-axis acceleration data or 3-axis angular rate data.

[0072] In certain embodiments, controller **160** may be directly coupled to IMU **168** using a serial communications interface, such as a serial peripheral interface (SPI), inter-integrated circuit

(I.sup.2C) interface, etc. (as depicted in FIG. **4**). In other embodiments, IMU **168** may be coupled to communications bus **169**. IMU **168** outputs the IMU sensor data to controller **160** for further processing. Additionally, controller **160** or IMU **168** may provide the IMU sensor data to memory **162** for storage as timestamped data.

[0073] In certain embodiments, the IMU microcontroller may process the **3**-axis acceleration data to determine a peak absolute acceleration (PAA) for each axis over a time period, such as 50 ms, 100 ms, 500 ms, 1 second, 3 seconds, etc., and output the PAA for each axis to controller **160**. Similarly, the IMU microcontroller may process the 3-axis angular rate data to determine a peak absolute angular rate (PAAR) for each axis over the time period, and output the PAAR for each axis to controller **160**. The IMU microcontroller may also determine other characteristics of the 3-axis acceleration data and the 3-axis angular rate data, such as a mean absolute acceleration, an average absolute acceleration, a mean absolute angular rate, an average absolute angular rate, etc.

[0074] In other embodiments, controller **160** may process the 3-axis acceleration data to determine the PAA for each axis over a time period, such as 50 ms, 100 ms, 500 ms, 1 second, 3 seconds, etc. Similarly, controller **160** may process the 3-axis angular rate data to determine the PAAR for each axis over the time period. Controller **160** may also determine other characteristics the 3-axis acceleration data (for each axis) and the 3-axis angular rate data, such as a mean absolute acceleration, an average absolute acceleration, a mean absolute angular rate, an average absolute angular rate, etc.

[0075] Additionally, the microcontroller of IMU **168** or controller **160** may also determine aggregate characteristics of the 3 axis acceleration data and the 3-axis angular rate data, such as an aggregate peak absolute acceleration (APAA) for all 3 axes, an aggregate peak absolute angular rate (APAAR) for all 3 axes, etc. For example, the APAA may be determined by summing the PAA for each axis, by calculating the square root of the sum of the squares of the PAA for each axis, etc. Similarly, the APAAR may be determined by summing the PAAR for each axis, by calculating the square root of the sum of the squares of the PAAR for each axis, etc.

[0076] Generally, controller **160** is configured to determine power tool information based on the IMU sensor data, such as an operational state, an operational time, a cumulative operational time, an operational parameter, a timestamped tool operational event, etc., as discussed below (FIGS. **8**A to **8**D, **9**A to **9**D, **10**, and **11**). In certain embodiments, controller **160** is configured to determine power tool information based on both 3-axis acceleration data and 3-axis angular rate data, while in other embodiments, controller **160** is configured to determine power tool information based on either 3-axis acceleration data or 3-axis angular rate data.

[0077] In certain embodiments, the microcontroller of IMU **168** may be configured to determine power tool information based on the IMU sensor data. In other embodiments, controller **160** and the microcontroller of IMU **168** may cooperate to determine power tool information based on the IMU sensor data. In other words, the functionality described below may be performed by controller **160**, the microcontroller of IMU **168**, or a combination of controller **160** and the microcontroller of IMU **168**.

[0078] The operational state of a power tool may include a rest state, a non-operating movement state, an unloaded operational state, a loaded operational state, etc. The operational time refers to a duration of time where the power tool is in a certain operational state. For example, the operational time may include a rest time, a non-operating movement time, an unloaded operational time, a loaded operational time, etc.

[0079] The cumulative operational time may include a cumulative rest time, a cumulative non-operating movement time, a cumulative unloaded operational time, a cumulative loaded operational time, etc. The operational parameters may include a type of power tool, a type of operation being performed by the power tool, a type of accessory mounted to the power tool, etc. The timestamped tool operational event may include a total operational time, a high loaded operational time, a low loaded operational time, a trigger press time, a trigger release time, and an idle time, etc.

[0080] WCU **164** may include a Bluetooth/BLE IC, module, SoC, etc. that includes a processor, memory, a Bluetooth transceiver, etc., a WiFi module, a communications interface, etc. WCU **164** may be configured to be coupled to network **410**, and controller **160** may communicate with WCU **164** to send and receive data over network **410**. For example, controller **160** may send the timestamped IMU sensor data stored in memory **162** to WCU **164** for communication over network **410**.

[0081] As discussed below (FIGS. **8**A to **8**D, **9**A to **9**D, and **10**), controller **160** may send the power tool information to WCU **164** for transmission over network **410** to tool monitoring device **420** and tool monitoring system **430**.

[0082] In certain embodiments, WCU **164** may be configured to be directly coupled to WCU **124** of power tool **400** over a Bluetooth communication link (dashed line in FIG. **4**), and controller **160** may communicate with WCU **164** to send and receive data over the Bluetooth communication link.

[0083] In other embodiments, auxiliary wireless device **150** may include serial communications unit (SCU) **166** (such as a USB module, an RS-232 module, etc.). In certain embodiments, SCU **166** may be configured to be directly coupled to SCU **126** of power tool **400** when mounted within the power tool housing (dashed line in FIG. **4**). Controller **160** may communicate with SCU **166** to send and receive data over a serial communication link to SCU **126** of power tool **400**.

[0084] In certain embodiments, controller **160** may send certain IMU sensor data and power tool information to WCU **164** or SCU **166** for transmission to power tool **400** for further processing or action, such as for adjusting its operating parameters, such as lowering motor current, shutting down power tool **400** when a parameter associated with the acceleration data (such as the peak absolute value of one or more axes of the 3-axis acceleration data) exceeds a certain threshold, etc.

[0085] Network **410** may include one or more local area networks, wide area networks, the Internet, etc., which may execute various network protocols, such as, for example, wired and/or wireless Ethernet, Bluetooth, etc. Network **410** may also include various combinations of wired and/or wireless physical layers, such as, copper wire or coaxial cable networks, fiber optic networks, Bluetooth wireless networks, WiFi wireless networks, CDMA, FDMA and TDMA cellular wireless networks, etc.

[0086] Generally, tool monitoring device **420** receives, stores, and displays power tool information received over network **410** (or a direct Bluetooth connection) from auxiliary wireless device **150**. Tool monitoring device **420** may include, inter alia, a bus, one or more processors (such a central processing unit (CPU) with one or more cores, a graphics processing unit (GPU), etc.), memory, one or more wireless network interfaces coupleable to network **410**, a touchscreen display, etc. Depending on the communication technique, tool monitoring device **420** may be remote device (communicating through network **410**) or a local device (communicating through direct Bluetooth or any other short range communication connection), such as a portable or laptop computer, a smartphone, etc.

[0087] Generally, tool monitoring system **430** receives, stores, and displays power tool information received over network **410** from auxiliary wireless device **150**. Tool monitoring system **430** may include, inter alia, a bus, one or more processors (such a central processing unit (CPU) with one or more cores, a GPU, etc.), memory, one or more network interfaces configured to be coupled to network **410**, etc. In certain embodiments, tool monitoring system **430** may also include input/output (I/O) devices, such as a keyboard, mouse, display(s), etc. Tool monitoring system **430** may be a remote device, such as a laptop or desktop computer, a network server, etc. Tool monitoring system **430** may provide a power tool inventory and operational database for security, maintenance, and other purposes, assess user productivity and efficiency, assess the health of the tool, etc., based on the information received from auxiliary wireless device **150**.

[0088] Model training system **440** may include, inter alia, a bus, one or more processors (such as central processing units (CPUs) with one or more processing cores, a GPU, etc.), memory, one or more network interfaces configured to be coupled to network **410**, etc. In certain embodiments, model training system **440** may include special purpose processors, such as one or more neural processing units (NPUs), etc., and may also include I/O devices, such as a keyboard, mouse, display(s), etc. Model training system **440** is generally considered to be remote device, such as a desktop computer, a network server, etc. The functionality provided by model training system **440** is discussed in more detail below (FIG. **9**E).

[0089] FIGS. **5**A to **5**F depict inertial measurement unit (IMU) sensor data plots for power tool **100** depicted in FIG. **1**, in accordance with embodiments of the present disclosure. As discussed above, IMU sensor data may be used to determine power tool information, such as operational state, operational time, cumulative operational time, operational parameters, etc. Data plots **500** depict 3-axis acceleration data for power tool **100** during rest, non-operating movement, unloaded operational state, and loaded operational state. Similarly, data plots **505** depict 3-axis angular rate data for power tool **100** during rest, non-operating movement, unloaded operational state, and loaded operational state. Additionally, specific power tool parameters such as the output speed and/or the impact rate of the output may be estimated based on the IMU sensor data. Various characteristics of these data are discussed below.

[0090] FIG. **5**A depicts IMU sensor data plots **500**, **505** for power tool **100** (impact driver) during operations of the tool in loaded, unloaded, movement and rest states, in accordance with embodiments of the present disclosure.

[0091] IMU sensor data plot **500** presents 3-axis acceleration data (g) over time (about 60 seconds) including 1.sup.st axis acceleration data **501**, 2.sup.nd axis acceleration data **502**, and 3.sup.rd axis acceleration data **503**. IMU sensor data plot **505** presents 3-axis angular rate data (degrees/sec) over time (about 60 seconds) including 1.sup.st axis angular rate data **506**, 2.sup.nd axis angular rate data **507**, and 3.sup.rd axis angular rate data **508**. In this figure, acceleration data **501**, **502**, **503** are overlapped on a first plot and angular rate data **506**, **507**, **508** are overlapped on a second plot.

[0092] FIG. **5**B depicts individual IMU sensor data plots **500**, **505** for power tool **100** during operations of the tool in loaded, unloaded, movement and rest states, in accordance with embodiments of the present disclosure. Here, acceleration data **501**, **502**, **503** are shown on three discrete plot lines and angular rate data **506**, **507**, **508** are shown on three discrete plot lines.

[0093] As discussed, plots **500**, **505** reflect IMU sensor data corresponding to the operation of power tool **100** operating in known operational states over **60** seconds, including rest state **510**, non-operating movement state **520**, non-operating movement state **530**, non-operating movement state **540**, non-operating movement state **550**, unloaded operational state **560**, and loaded operational state **570**.

[0094] During rest state **510**, power tool **100** is at rest (but not activated). The associated rest time **511** is about 4 seconds. During non-operating movement state **520**, power tool **100** is picked up and hooked to the user's belt (but not activated). The associated non-operating movement time **521** is about 3 seconds in this example. During non-operating movement state **530**, power tool **100** is hooked to the user's belt while walking (but not activated). The associated non-operating movement time **531** is about 8 seconds in this example. During non-operating movement state **540**, power tool **100** is hooked to the user's belt while climbing a ladder (but not activated). The associated non-operating movement time **541** is about 6 seconds in this example. During non-operating movement state **550**, power tool **100** is hooked to the user's belt while descending the ladder (but not activated). The associated non-operating movement time **551** is about 5 seconds in this example. During unloaded operational state **560**, trigger **111** is activated in an unloaded condition with output accessory **102** (socket) attached. The associated unloaded operational time **561** is about 3 seconds. During loaded operational state **570**, trigger **111** is activated in a loaded condition with output accessory **102** (socket) attached. The associated loaded operational time **571** is about 4 seconds.

[0095] The 3-axis acceleration data, and to a lesser extent the 3-axis angular rate data, provide insights into the acceleration and angular rate environments of power tool **100** during the known operational states.

[0096] During rest state **510**, the peak absolute acceleration value of all 3 axes is less than or equal to 1 g, and the peak absolute angular rate value of all 3 axes is substantially close to 0 degrees/sec.
[0097] During non-operating movement states **520**, **530**, **540**, **550**, the movement observable in the 3-axis acceleration data exhibits either a non-uniform pattern corresponding to sudden and isolated movements of the power tool, or a patterned behavior corresponding to movement of the power tool due to walking or climbing, but one having a frequency that is significantly smaller than a frequency seen during an operating state of the power tool. For example, during non-operating movement state **530**, a walking cadence may be observed in at least one axis of the 3-axis acceleration data, but the frequency of the walking cadence (e.g., smaller than or equal to approximately 7 Hz) will be significantly lower than a frequency domain of an operating state of the power tool (e.g., greater than or equal to approximately 15 Hz). During non-operating movement state **540**, a climbing cadence may be observed in at least one axis of the 3-axis acceleration data corresponding to each step of the climb, but once again the frequency of the climbing cadence will be significantly lower than the frequency domain of the operating state of the power tool. During non-operating movement state **550**, a descending cadence may be observed in at least one axis of the 3-axis acceleration data with a similarly small frequency Furthermore, the magnitude of the 3-axis accelerometer data is significantly smaller than a magnitude seen during an operating of the power tool.
[0098] In an embodiment, during the non-operating movement states **520**, **530**, **540**, **550**, a repeated pattern of each of the individual 3-axis acceleration data **501**, **502**, **503** plot lines remains within a pre-determined non-operating acceleration movement zone defined by an upper threshold and a lower threshold (e.g., +3 to −3 G). Similarly, a repeated pattern each of the individual 3-axis angular rate data **506**, **507**, **508** plot lines remain within a pre-determined non-operating angular rate movement zone defined by an upper threshold and a lower threshold (e.g., approximately +100 to −100 degrees/sec). Furthermore, during the non-operating movement states **520**, **530**, **540**, **550**, at least where a patterned behavior is exhibited, the sum of the amplitudes of the 3-axis acceleration data **501**, **502**, **503** remains within a predetermined non-operating acceleration movement zone (e.g., approximately +6 to −6 G) and the sum of the 3-axis angular rate data **506**, **507**, **508** remains within a predetermined non-operating angular rate movement zone (e.g., approximately +100 to −100 degrees/sec). Moreover, during the non-operating movement states **520**, **530**, **540**, **550**, at least where a patterned behavior is exhibited, the RMS (Room Mean Square) of the amplitudes of the 3-axis acceleration data **501**, **502**, **503** remains within a predetermined non-operating acceleration movement RMS zone and the RMS of the 3-axis angular rate data **506**, **507**, **508** remains within a predetermined non-operating angular rate movement RMS zone.
[0099] Controller **160** may use any of these parameters or combinations thereof to distinguish between the non-operating movement state of the power tool and a rested state of power tool **100** as previously discussed, and an operational state of the power tool as discussed below. Controller **160** may also detect occurrences of isolated and unrepeated events (such as, e.g., lifting the tool from the stationary position, securing the tool to the user's belt, removing the tool from the user's belt, etc.) within the non-operating movement state based on isolated high-amplitude spikes in one or more of the 3-axis acceleration data **501**, **502**, **503** and/or the 3-axis angular rate data **506**, **507**, **508**.
[0100] During unloaded operational state **560**, the peak absolute value (i.e., peak amplitude) of at least two axes of the acceleration data is greater than 2 g over a 50 ms window (see FIG. **5**D, 1.sup.st axis acceleration data **501** and 2.sup.nd axis acceleration data **502**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with an unloaded output shaft speed. The frequency of the at least two axes of the acceleration data is greater than approximately 15 Hz, preferably greater than approximately 20 Hz. The 3-axis angular rate data additionally includes a sinusoidal waveform visible on the axis of motor rotation with a frequency (40 Hz) that aligns with an unloaded output shaft speed (2,400 rpm) (see FIG. **5**D,

2.sup.nd axis angular rate data).
[0101] During loaded operational state **570**, the peak absolute value of all axes of the 3-axis acceleration data is greater than 6 g over a 50 ms window (see FIG. **5**F). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency (56 Hz) that aligns with the impact rate of the impactor assembly (˜3,400 impacts per minute or ipm). Intermediate, smaller peaks are observable that represent hammer rebound of the impactor assembly. The frequency of the acceleration data is greater than approximately 15 Hz, preferably greater than approximately 20 Hz. The 3-axis angular rate data also exhibits significantly higher amplitude in comparison to the non-operating movement states **520**, **530**, **540**, **550**.
[0102] FIG. **5**C depicts IMU sensor data plots **500**, **505** for power tool **100** during operation of the tool in the unloaded operational state, in accordance with embodiments of the present disclosure.
[0103] IMU sensor data plot **500** presents 3-axis acceleration data (g) over unloaded operational state **560** including 1.sup.st axis acceleration data **501**, 2.sup.nd axis acceleration data **502**, and 3.sup.rd axis acceleration data **503**. IMU sensor data plot **505** presents 3-axis angular rate data (degrees/sec) over unloaded operational state **560** including 1.sup.st axis angular rate data **506**, 2.sup.nd axis angular rate data **507**, and 3.sup.rd axis angular rate data **508**.
[0104] An example partial unloaded operational state window **562** (over about 0.25 seconds) is also identified to provide a zoomed-in and detailed view of the IMU sensor data plot in the unloaded operational state in the next figure (FIG. **5**D). As shown here, and with continued reference to FIGS. **5**A and **5**B, the amplitude of the acceleration data in the unloaded operational state far exceeds the amplitude of the acceleration data in the non-operating movement states **520**, **530**, **540**, **550**, but the amplitude is substantially smaller than the amplitude of the acceleration data in loaded operational state **570**. This information may be used by controller **160** to differentiate between these states. Further, the angular rate data does not exhibit a high amplitude, and in fact exhibits a lower amplitude than both non-operating movement states **520**, **530**, **540**, **550** as well as loaded operational state **570**. This is due to the operator holding the tool still during this particular test example. However, this observation may be used by controller **160** as another data point to distinguish between loaded and unloaded operational states.
[0105] FIG. **5**D depicts IMU sensor data plots **500**, **505** for power tool **100** during operation of the tool in the unloaded operational state within the partial unloaded operational state window **562**, in accordance with embodiments of the present disclosure.
[0106] IMU sensor data plot **500** individually presents 3-axis acceleration data (g) over partial unloaded operational state window **562** including 1.sup.st axis acceleration data **501**, 2.sup.nd axis acceleration data **502**, and 3.sup.rd axis acceleration data **503**. IMU sensor data plot **505** individually presents 3-axis angular rate data (degrees/sec) over partial unloaded operational state window **562** including 1.sup.st axis angular rate data **506**, 2.sup.nd axis angular rate data **507**, and 3.sup.rd axis angular rate data **508**. Second axis angular rate data **507** includes a sinusoidal waveform visible on the axis of motor rotation with a frequency (40 Hz) that aligns with an unloaded output shaft speed (2,400 rpm). The sinusoidal waveform is associated with a rotating mass located in the hammering mechanism of the impact wrench, which causes an imbalance in the rotation of the output shaft. Controller **160** may rely on detection of this sinusoidal waveform on at least one of the angular rate data plot lines as yet another data point used to distinguish between unloaded operational state **560** and the other states, such as such as loaded operational state **570**, non-operating movement states **520**, **530**, **540**, **550**, rest state **510**, etc.
[0107] In an example, the detected frequency of this sinusoidal waveform may also be used by controller **160** to estimate the unloaded rotational speed of the output shaft. For example, controller **160** may be configured to detect a sinusoidal pattern on one or more of the angular rate data waveforms (e.g., where a peak of the waveform exceeds a threshold of 100 degrees/sec), calculate the frequency of the waveform with the detected sinusoidal pattern, and estimate the unloaded rotational speed of the shaft as a function of the calculated frequency. This information may be

wirelessly relayed by controller **160**.

[0108] FIG. **5**E depicts IMU sensor data plots **500**, **505** for power tool **100** during operation of the tool in the loaded operational state, in accordance with embodiments of the present disclosure.

[0109] IMU sensor data plot **500** presents 3-axis acceleration data (g) over loaded operational state **570** including 1.sup.st axis acceleration data **501**, 2.sup.nd axis acceleration data **502**, and 3.sup.rd axis acceleration data **503**. IMU sensor data plot **505** presents 3-axis angular rate data (degrees/sec) over loaded operational state **570** including 1.sup.st axis angular rate data **506**, 2.sup.nd axis angular rate data **507**, and 3.sup.rd axis angular rate data **508**.

[0110] An example partial loaded operational state window **572** (over about 0.25 seconds) is also identified to provide a zoomed-in and detailed view of the IMU sensor data plot in the loaded operational state in the next figure (FIG. **5**F). As shown here in this example, and with continued reference to FIGS. **5**A and **5**B, the amplitude of the acceleration data on all three axes is substantially greater than the amplitude of the acceleration data in unloaded operational state **560**. Similarly, the amplitude of the angular rate data on at least two axes is substantially greater than the amplitude of the angular rate data in unloaded operational state **560**. This information may be used by controller **160** to differentiate between loaded operational state **570** and the other states, such as rest state **510**, non-operating movement states **520**, **530**, **540**, **550**, and unloaded operational state **560**.

[0111] The acceleration data for all three axes include many positive and negative local peak values, and indicate periodically changing signals that may include sinusoidal components. The average of the positive local peak values for each axis is at least 4 g, while the average of the negative local peak values for each axis is at least −4 g. In other words, the average of the absolute values of the positive and negative local peak values for each axis is at least 4 g. The acceleration data for at least one of the axes has an average absolute local peak value of at least 8 g, such as 1 .sup.st axis acceleration data **501** and 2.sup.nd axis acceleration data **502**. An envelope formed by connecting the absolute local peak values for at least one axis has an average value of at least 10 g, such as 1.sup.st axis acceleration data **501**. Similarly, for the angular rate data, an envelope formed by connecting the absolute local peak values for at least one axis has an average value of at least 2,000 degrees/sec, such as 2.sup.nd axis angular rate data **507**. Additionally, the angular rate data for at least one least one axis has an average absolute peak value that is substantially greater than the average absolute peak value for at least one other axis. In another example, 1.sup.st axis angular rate data **506** or 2.sup.nd axis angular rate data **507** may be determined to be at least twice the average absolute peak value of 3.sup.rd axis angular rate data **507** (such as at least three times the average absolute peak value). This information may be used by controller **160** to further differentiate between loaded operational state **570** and the other states, such as rest state **510**, non-operating movement states **520**, **530**, **540**, **550**, and unloaded operational state **560**.

[0112] FIG. **5**F depicts IMU sensor data plots **500**, **505** for power tool **100** during operation of the tool in the loaded operational state within the partial operational state window **572**, in accordance with embodiments of the present disclosure.

[0113] IMU sensor data plot **500** individually presents 3-axis acceleration data (g) over loaded operational state window **572** including 1.sup.st axis acceleration data **501**, 2.sup.nd axis acceleration data **502**, and 3.sup.rd axis acceleration data **503**. IMU sensor data plot **505** individually presents 3-axis angular rate data (degrees/sec) over loaded operational state window **572** including 1.sup.st axis angular rate data **506**, 2.sup.nd axis angular rate data **507**, and 3.sup.rd axis angular rate data **508**. All three axes of the 3-axis acceleration data indicate sinusoidal behavior with a frequency (56 Hz) that aligns with the impact rate of the impactor assembly (˜3,400 impacts per minute or ipm). See, for example, 2.sup.nd axis acceleration data **502**. Intermediate, smaller peaks are observable that represent hammer rebound of the impactor assembly. In an example, the detected frequency of this sinusoidal waveform may be used by controller **160** to estimate the loaded impact rate of the output shaft. Controller **160** may rely on detection of this sinusoidal waveform on one or more of the acceleration plot lines as yet another data point used to distinguish between loaded operational state **570** and the other states, such as unloaded operational state **560**, non-operating movement states **520**, **530**, **540**, **550**, rest state **510**, etc.

[0114] In an example, the detected frequency of this sinusoidal waveform on the accelerometer waveforms may also be used by controller **160** to estimate the loaded impact rate of the output shaft. For example, controller **160** may be configured to detect a sinusoidal pattern on one or more of the acceleration date waveforms (e.g., where a peak of the waveform exceeds a threshold of 4 g), calculate the frequency of the waveform with the detected sinusoidal pattern, and estimate the loaded impact rate of the shaft as a function of the calculated frequency. This information may be wirelessly relayed by controller **160**.

[0115] FIGS. **6**A to **6**J depict IMU sensor data plots **600**, **605** for power tool **200**, in accordance with embodiments of the present disclosure. As discussed above, IMU sensor data may be used to determine power tool information, such as operational state, operational time, cumulative operational time, operational parameters, etc. Data plots **600** depict 3-axis acceleration data for power tool **200** during unloaded and loaded operational states (3-axis acceleration data for rest and non-operating movement states will be similar to the data presented for power tool **100** in data plots **500**). Similarly, data plots **605** depict 3-axis angular rate data for power tool **100** during unloaded and loaded operational states (3-axis angular rate data for rest and non-operating movement states will be similar to the data presented for power tool **100** in data plots **505**). Power tool **200**, which in this example is an angle grinder, is utilized herein to highlight capabilities of controller **160** to distinguish between types of power tool to which the auxiliary wireless device **150** is mounted.

[0116] Specifically, as discussed below in detail, the IMU sensor data plots **600** and **605** exhibit unique characteristics that are discernable from characteristics of the IMU sensor data plots **500** and **505** when using an impact wrench, and they can be used by controller **160** to identify the type of power tool (e.g., angle grinder versus impact wrench) to which the auxiliary wireless device **150** is coupled. Further highlighted below are capabilities of controller **160** to identify the type of power tool accessory mounted onto the power tool (e.g., type of grinding disc), and the type of operation being performed by the accessory (e.g., heavy versus light grinding). Various characteristics of these data are discussed below.

[0117] FIG. **6**A depicts IMU sensor data plots **600**, **605** for power tool **200** (angle grinder) during operation of the tool in the unloaded and loaded operational states, in accordance with embodiments of the present disclosure.

[0118] IMU sensor data plot **600** presents 3-axis acceleration data (g) over time (about 70 seconds) including 1.sup.st axis acceleration data **601**, 2.sup.nd axis acceleration data **602**, and 3.sup.rd axis acceleration data **603**. IMU sensor data plot **605** presents 3-axis angular rate data (degrees/sec) over time (about **70** seconds) including 1.sup.st axis angular rate data **606**, 2.sup.nd axis angular rate data **607**, and 3.sup.rd axis angular rate data **608**. In this figure, acceleration data **601**, **602**, **603** are overlapped on a first plot and angular rate data **606**, **607**, **608** are overlapped on a second plot.

[0119] FIG. **6**B depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in the unloaded and loaded operational states, in accordance with embodiments of the present disclosure. Here, acceleration data **601**, **602**, **603** are shown on three discrete plot lines and angular rate data **606**, **607**, **608** are shown on three discrete plot lines.

[0120] Plots **600**, **605** reflect IMU sensor data corresponding to the operation of power tool **200** operating in known operational states over 70 seconds, including unloaded operational state **660**, heavy loaded operational state **670**.**1**, light loaded operational state **670**.**2**, and loaded operational state **670**.**3** (using an alternative grinding disc).

[0121] During unloaded operational state **660**, paddle trigger **211** is activated in an unloaded condition with output accessory **202** (e.g., a 4.5″ abrasive grinding disc) attached. The associated unloaded operational time **661** is about 2 seconds in this example. During heavy loaded operational state **670.1**, paddle trigger **211** is activated in a loaded condition (heavy grinding) with output accessory **102** (the 4.5″ abrasive grinding disc) attached. The associated loaded operational time **671.1** is about 6 seconds in this example. During light loaded operational state **670.2**, paddle trigger **211** is activated in a loaded condition (light grinding on an alternative workpiece or on the same workpiece with application of less force) with output accessory **102** (the 4.5″ abrasive grinding disc) attached. The associated loaded operational time **671.2** is about 6 seconds in this example. During loaded operational state **670.3** (using an alternative grinding disc), paddle trigger **211** is activated in a loaded condition (light material removal) with output accessory **102** (**80**-grit flap disc) attached. The associated loaded operational time **671.3** is about 6 seconds in this example.

[0122] The 3-axis acceleration data and the 3-axis angular rate data provide insights into the acceleration and angular rate environments of power tool **200** during the known operational states.

[0123] During unloaded operational state **660**, the peak absolute value of at least two axes of the acceleration data is greater than 4 g over a 50 ms window (see FIG. **6**D, 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency (128 Hz) that aligns with an unloaded output shaft speed (7,800 rpm). More visibly, the 3-axis angular rate data includes sinusoidal waveforms visible on all three axes with a frequency (128 Hz) that aligns with an unloaded output shaft speed (7,800 rpm) (see FIG. **6**D).

[0124] During heavy loaded operational state **670.1**, the peak absolute value of at least two axes of the acceleration data is greater than 12 g over a 50 ms window (see FIG. **6**F, 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with unloaded output shaft speed. The 3-axis angular rate data may include a similar frequency component, and the peak absolute value of at least one axis of the angular rate data exceeds 180 degrees/sec. Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (4 Hz) that aligns with user-induced movement (see FIG. **6**F, 3.sup.rd axis angular rate data **608**) commonly associated with a heavy grinding operation. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz.

[0125] During light loaded operational state **670.2**, the peak absolute value of at least two axes of the acceleration data is greater than 8 g over a 50 ms window (see FIG. **6**H, 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with unloaded output shaft speed. The 3-axis angular rate date may include a similar frequency component. The peak absolute value of at least one axis of the angular rate data exceeds approximately 160 degrees/sec. Overall, the acceleration data and the angular rate data may include similar frequencies exhibited during loaded operational state **670.1**, but with smaller overall amplitudes. This distinction may be determined as a difference between the peak absolute values, between the average amplitudes, between the RMS amplitude values, or as a function of an area of an envelope defined by the peak values. Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (4 Hz) that aligns with user-induced movement (see FIG. **6**H, 3.sup.rd axis angular rate data **608**) commonly associated with a light grinding operation. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz.

[0126] During loaded operational state **670.3** (using an alternative grinding disc), the peak absolute value of at least two axes of the acceleration data is greater than 4 g but smaller than 8 g over a 50 ms window (see FIG. **6**J, 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with unloaded output shaft speed. The **3**-axis angular rate date may include a similar frequency component. The peak absolute value of at least one axis of the angular rate data is smaller than 160 degrees/sec. Overall, the acceleration data and the angular rate data may include similar frequency components exhibited during loaded operational state **670.1**, but with smaller overall amplitudes. The 3-axis angular rate data further exhibits a sinusoidal pattern visible on at least two axes with a frequency (3 Hz) that aligns with user-induced movement (see FIG. **6**J, 3.sup.rd axis angular rate data **608**) commonly associated with a flap disc grinding operation. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz.

[0127] FIG. **6**C depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in unloaded operational state **660** in accordance with embodiments of the present disclosure.

[0128] IMU sensor data plot **600** presents 3-axis acceleration data (g) over unloaded operational state **660** including 1.sup.st axis acceleration data **601**, 2.sup.nd axis acceleration data **602**, and 3.sup.rd axis acceleration data **603**. IMU sensor data plot **605** presents 3-axis angular rate data (degrees/sec) over unloaded operational state **660** including 1.sup.st axis angular rate data **606**, 2.sup.nd axis angular rate data **607**, and 3.sup.rd axis angular rate data **608**.

[0129] An example partial unloaded operational state window **662** (over about 0.25 seconds) is also identified to provide a zoomed-in and detailed view of the IMU sensor data plot in the unloaded operational state in the next figure (FIG. **6**D). As shown here in this example, the amplitude of the acceleration data in unloaded operational state **660** far exceeds the amplitude of the acceleration data in the preceding time period of non-operating movement or rest (from 0 seconds to about 5 seconds), and is generally two to three times smaller than the amplitude of the acceleration data in loaded operational state **670**. Similarly, the amplitude of the angular rate data in unloaded operational state **660** far exceeds the amplitude of the angular rate data in the preceding time period of non-operating movement or rest, and is generally two to three times smaller than the amplitude of the acceleration data in loaded operational state **670**. This information may be used by controller **160** to further differentiate between unloaded operational state **660** and other states, such as the rest state, the non-operating movement states, and loaded operational state **670**.

[0130] FIG. **6**D depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in the unloaded operational state **660** within the example partial unloaded operational state window **662**, in accordance with embodiments of the present disclosure.

[0131] IMU sensor data plot **600** individually presents 3-axis acceleration data (g) over partial unloaded operational state window **662** including 1.sup.st axis acceleration data **601**, 2.sup.nd axis acceleration data **602**, and 3.sup.rd axis acceleration data **603**. IMU sensor data plot **605** individually presents 3-axis angular rate data (degrees/sec) over partial unloaded operational state window **662** including 1.sup.st axis angular rate data **606**, 2.sup.nd axis angular rate data **607**, and 3.sup.rd axis angular rate data **608**. The 3-axis angular rate data includes sinusoidal waveforms visible on all three axes with a frequency (128 Hz) that aligns with an unloaded output shaft speed (7,800 rpm).

[0132] As shown in FIGS. **6**C and **6**D, and previously described, during unloaded operational state **660**, the peak absolute value of at least two axes of the acceleration data is greater than approximately 4 g over a 50 ms window (see 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**), but the peak absolute value of all three axes of the acceleration data is smaller than approximately 6 g. Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency (128 Hz) that aligns with an unloaded output shaft speed (7,800 rpm).

[0133] Furthermore, the 3-axis angular rate data includes sinusoidal waveforms visible on all three axes with a frequency (128 Hz) that aligns with an unloaded output shaft speed (7,800 rpm). The absolute peak of the 3-axis angular rate data is in the range of approximately 80 degrees/sec. In other words, both the 3-axis acceleration data and the 3-axis angular rate data form a profile (i.e., formed by the absolute peak of the waveform with the highest amplitude, the sum of the three axes waveform, the RMS values, etc.) that is greater than a similar profile formed in the rest state, but is less than a similar profile formed in loaded operational states **670.1**, **670.2**, **670.3**. Controller **160** may use any or all of this information to distinguish between an unloaded operational state **660** and the other states, such as loaded operational states **670.1**, **670.2**, **670.3**.

[0134] FIG. **6**E depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in the heavy loaded operational state **670.1**, in accordance with embodiments of the present disclosure. In this figure, acceleration data **601**, **602**, **603** are overlapped on a first plot and angular rate data **606**, **607**, **608** are overlapped on a second plot.

[0135] FIG. **6**F depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in the heavy loaded operational state **670.1**, in accordance with embodiments of the present disclosure. Here, acceleration data **601**, **602**, **603** are shown on three discrete plot lines and angular rate data **606**, **607**, **608** are shown on three discrete plot lines.

[0136] IMU sensor data plot **600** individually presents 3-axis acceleration data (g) over loaded operational state **670.1** including 1.sup.st axis acceleration data **601**, 2.sup.nd axis acceleration data **602**, and 3.sup.rd axis acceleration data **603**. IMU sensor data plot **605** individually presents 3-axis angular rate data ((degrees/sec) over loaded operational state **670.1** including 1.sup.st axis angular rate data **606**, 2.sup.nd axis angular rate data **607**, and 3.sup.rd axis angular rate data **608**. The 3-axis angular rate data includes sinusoidal waveforms visible on the all three axes with a frequency (4 Hz) that aligns with user-induced movement, such as 3.sup.rd axis angular rate data **608**. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz.

[0137] As shown here and previously described, during heavy loaded operational state **670.1**, the peak absolute value of at least two axes of the acceleration data is greater than 12 g over a 50 ms window (see 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with unloaded output shaft speed. The 3-axis angular rate data may include a similar frequency component, and the peak absolute value of at least one axis of the angular rate data exceeds **200** degrees/sec.

[0138] Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (4 Hz) that aligns with user-induced movement (see 3.sup.rd axis angular rate data **608**) commonly associated with a heavy grinding operation. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz. Controller **160** may use any or all of this information to distinguish between heavy loaded operational state **670.1** and the other loaded operational states, such as light loaded operational state **670.2** and loaded operational state **670.3** (using an alternative grinding disc). In other words, one or both of the frequency and/or an amplitude profile (i.e., formed by the absolute peak of the waveform with the highest amplitude, the sum of the three axes waveform, the RMS values, etc.) of one or both of the acceleration data and/or the angular rate data can be used by controller **160** to distinguish between levels of grinding operation (i.e., light versus heavy) when using a single grinding disc. In an example, controller **160** may detect the grinding operation, classify the grinding operation into one of a preset number of load levels (e.g., in this example, light versus heavy), and wirelessly communication the classification.

[0139] FIG. **6**G depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in the light loaded operational state **670.2**, in accordance with embodiments of the present disclosure. In this figure, acceleration data **601**, **602**, **603** are overlapped on a first plot and angular rate data **606**, **607**, **608** are overlapped on a second plot.

[0140] FIG. **6**H depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in the light loaded operational state **670.2**, in accordance with embodiments of the present disclosure. Here, acceleration data **601**, **602**, **603** are shown on three discrete plot lines and angular rate data **606**, **607**, **608** are shown on three discrete plot lines.

[0141] IMU sensor data plot **600** individually presents 3-axis acceleration data (g) over loaded operational state **670.2** including 1.sup.st axis acceleration data **601**, 2.sup.nd axis acceleration data **602**, and 3.sup.rd axis acceleration data **603**. IMU sensor data plot **605** individually presents 3-axis angular rate data (degrees/sec) over loaded operational state **670.2** including 1.sup.st axis angular rate data **606**, 2.sup.nd axis angular rate data **607**, and **3**.sup.rd axis angular rate data **608**. The 3-axis angular rate data includes sinusoidal waveforms visible on the all three axes with a frequency (4 Hz) that aligns with user-induced movement, such as 3.sup.rd axis angular rate data **608**. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz.

[0142] As shown here and previously described, during light loaded operational state **670.2**, the peak absolute value of at least two axes of the acceleration data is in the range of approximately 8 to 12 g over a 50 ms window (see FIG. **6**H, 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with unloaded output shaft speed. The 3-axis angular rate date may include a similar frequency component, and the peak absolute value of at least one axis of the angular rate data is in the range of approximately 160 to 200 degrees/sec. Overall, the acceleration data and the angular rate data may include similar frequencies exhibited during the heavy loaded operational state **670.1**, but with smaller overall amplitudes. This distinction may be determined as a difference between the peak absolute values, between the average amplitudes, between the RMS amplitude values, or as a function of an area of an envelope defined by the peak values.

[0143] Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (4 Hz) that aligns with user-induced movement (see FIG. **6**H, **3**.sup.rd axis angular rate data **608**) commonly associated with a light grinding operation. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz. Controller **160** may use any or all of this information to distinguish between light loaded operational state **670.2** and the other loaded operational states, such as heavy loaded operational state **670.1** and loaded operational state **670.3** (using an alternative grinding disc).

[0144] FIG. **61** depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in loaded operational state **670.3** (using an alternative grinding disc), in accordance with embodiments of the present disclosure. In this figure, acceleration data **601**, **602**, **603** arc overlapped on a first plot and angular rate data **606**, **607**, **608** are overlapped on a second plot.

[0145] FIG. **6**J depicts IMU sensor data plots **600**, **605** for power tool **200** during operation of the tool in loaded operational state **670.3** (using an alternative grinding disc), in accordance with embodiments of the present disclosure. Here, acceleration data **601**, **602**, **603** are shown on three discrete plot lines and angular rate data **606**, **607**, **608** are shown on three discrete plot lines.

[0146] IMU sensor data plot **600** individually presents 3-axis acceleration data (g) over loaded operational state **670.3** including 1.sup.st axis acceleration data **601**, 2.sup.nd axis acceleration data **602**, and 3.sup.rd axis acceleration data **603**. IMU sensor data plot **605** individually presents 3-axis angular rate data (degrees/sec) over loaded operational state **670.3** including 1.sup.st axis angular rate data **606**, 2.sup.nd axis angular rate data **607**, and 3.sup.rd axis angular rate data **608**. The 3-axis angular rate data includes sinusoidal waveforms visible on the all three axes with a frequency (3 Hz) that aligns with user-induced movement, such as 3.sup.rd axis angular rate data **608**. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz.

[0147] As shown here and previously described, during loaded operational state **670.3** (using an alternative grinding disc), the peak absolute value of at least two axes of the acceleration data is greater than 4 g but smaller than 8 g over a 50 ms window (see 1.sup.st axis acceleration data **601** and 2.sup.nd axis acceleration data **602**). Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency that aligns with unloaded output shaft speed. The 3-axis angular rate date may include a similar frequency component. The peak absolute value of at least one axis of the angular rate data is smaller than 160 degrees/sec. Overall, the acceleration data and the angular rate data may include similar frequency components exhibited during loaded operational states **670**.**1** and **670**.**2**, but with smaller overall amplitudes. This distinction may be determined as a difference between the peak absolute values, between the average amplitudes, between the RMS amplitude values, or as a function of an area of an envelope defined by the peak values.

[0148] Additionally, the 3-axis angular rate data further exhibits a sinusoidal pattern visible on at least two axes with a frequency (3 Hz) that aligns with user-induced movement (see FIG. **6**J, 3.sup.rd axis angular rate data **608**) commonly associated with a flap disc grinding operation. This behavior is distinct from the user-induced movement exhibited when using the grinding disc during loaded operational states **670**.**1** and **670**.**2** and includes a more refined sinusoidal behavior along at least one of the axes. Generally, the user-induced movement of power tool **200** (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz. Controller **160** may use any or all of this information to distinguish between loaded operational state **670**.**3** (using an alternative grinding disc) and the other loaded operational states, such as heavy loaded operational state **670**.**1** and light loaded operational state **670**.**2**. In other words, one or both of the frequency and/or an amplitude profile (i.e., formed by the absolute peak of the waveform with the highest amplitude, the sum of the three axes waveform, the RMS values, etc.) of one or both of the acceleration data and/or the angular rate data can be used by controller **160** to distinguish between type of grinding operation (i.e., the type of disc utilized for the operation). In an example, controller **160** may detect the grinding operation, classify the grinding operation into one of a preset number of grinding operation types (e.g., in this example, grinding operation versus flap operation), and wirelessly communicate the classification.

[0149] Referring back to FIGS. **6**A and **6**B, it is noted that the accelerometer and angular rate data exhibit spikes between loaded operational states **670**.**2** and **670**.**3** (i.e., at approximately 28 seconds and again at approximately **50** seconds). This behavior is associated with the operator dismounting the existing grinding disc from the power tool and mounting a flap disc in its place. In an embodiment, controller **160** may detect this behavior between loaded operational states and use it for an additional data point for determination of whether a new accessory has been mounted onto the power tool.

[0150] Comparing FIGS. **5**A to **5**F and FIGS. **6**A to **6**J, it is further noted that there are several discernable differences between the acceleration and/or angular rate profiles of power tool **100** (impact wrench) and power tool **200** (angle grinder). These differences can be identified by controller **160** during tool usage to identify the type of power tool to which the auxiliary wireless device **150** is coupled. For example, power tool **200** exhibits a significantly higher acceleration and angular rate frequency associated with the higher output speed of an angle grinder. By contrast, power tool **100** exhibits a higher amplitude (i.e., in terms of the absolute peak, the sum of the 3-axes amplitudes, or the RMS value) associated with the higher vibration levels seen in impacting operations as compared to than grinding operations. These examples highlight only some of the differences between the acceleration and/or angular rate profiles of power tools **100** and **200** that can be detected by controller **160** to identify the type of power tool to which the auxiliary wireless device **150** is coupled. This arrangement is particularly beneficial where the auxiliary wireless device **150** does not have a direct connection (e.g., via SCU **166** or WCU **164**) to the power tool to obtain an identification information of the power tool.

[0151] FIGS. **7**A to **7**G depict IMU sensor data plots **700**, **705** for power tool **300** depicted in FIGS. **3**A, **3**B, **3**C, in accordance with embodiments of the present disclosure. As discussed above, IMU sensor data may be used to determine power tool information, such as operational state, operational time, cumulative operational time, operational parameters, etc. Data plots **700** depict 3-axis acceleration data for power tool **300** during an active non-cutting operational state and three cutting operational states will be similar to the data presented for power tool **100** in data plots **500**. Similarly, data plots **705** depict 3-axis angular rate data for power tool **300** during the active non-cutting and three cutting operational states will be similar to the data presented for power tool **100** in data plots **505**. The active non-cutting operational state occurs when trigger **311** is pressed and the electric motor is operating but accessory **302** (such as a cutting blade) is not cutting a workpiece (such as lumber material).

[0152] Power tool **300**, which in this example is a miter saw, is utilized herein to highlight capabilities of controller **160** to identify operations of a power tool based predominantly on a detection of a predetermined motion by the power tool. In particular, a miter saw is a stationary tool includes a heavy cutting accessory performing repeated cutting operations on a workpiece (such as lumber material). Generally, due to the high inertia of the cutting blade, the vibration profiles between a cutting operational state and the active non-cutting operational state may be discernible. However, the angular rate data can reliably be used to detect a cutting operation that includes a downward movement of the output accessory **302** followed by an upward movement of the output accessory **302**. Controller **160** can use this information to identify and keep count of cutting operations performed by power tool **300**, as discussed below in detail. Further highlighted below are capabilities of controller **160** to identify the type of power tool to which the auxiliary wireless device **150** is coupled, in this case, a stationary versus a portable power tool, and particularly, a power tool that is configured to conduct operations in a predictable and repeated pattern (e.g., a miter saw) versus other types of power tools. Various characteristics of these data are discussed below.

[0153] FIG. **7**A depicts IMU sensor data plots **700**, **705** for power tool **300** (miter saw) during operations of the tool in active non-cutting and cutting operational states, in accordance with embodiments of the present disclosure.

[0154] IMU sensor data plot **700** presents 3-axis acceleration data (g) over time (about 20 seconds) including 1.sup.st axis acceleration data **701**, 2.sup.nd axis acceleration data **702**, and 3.sup.rd axis acceleration data **703**. IMU sensor data plot **705** presents 3-axis angular rate data (degrees/sec) over time (about **20** seconds) including 1.sup.st axis angular rate data **706**, 2.sup.nd axis angular rate data **707**, and 3.sup.rd axis angular rate data **708**. In this figure, acceleration data **701**, **702**, **703** are overlapped on a first plot and angular rate data **706**, **707**, **708** are overlapped on a second plot.

[0155] FIG. **7**B depicts IMU sensor data plots **700**, **705** for power tool **300** during operations of the tool in active non-cutting and cutting operational states, in accordance with embodiments of the present disclosure.

[0156] Plots **700**, **705** reflect IMU sensor data corresponding to the operation of power tool **300** operating in known operational states over **20** seconds, including active non-cutting operational state **760**, and three subsequent cutting operational states **770**.**1**, **770.2**, and **770.3**. Active non-cutting operational state **760** may also be known as an unloaded operational state.

[0157] During active non-cutting operational state **760**, trigger **311** is activated and the miter saw **370** is held in the first position with output accessory **302** (cutting blade) attached. The associated operational time **761** is about 4 seconds in this example, at the end of which the trigger **331** is released. At the beginning of each cutting operational state **770**.**1**, trigger **311** is activated with output accessory **102** (cutting blade) attached, and miter saw **370** is rotated from the first position to the second position to engage the workpiece (2×4 SPF board). After the workpiece is cut, the miter saw **370** is rotated back to the first position, trigger **311** is released (deactivated), and the electric motor and output accessory **302** were allowed to coast down or brake to a stop. While the operational time **771**.**1** is about 5 seconds for the entire operation in this example, the actual cutting time is about 1 second and the associated unloaded operational time for moving the blade into engagement with the workpiece and back in its first position is about 4 seconds in this example.

[0158] The 3-axis acceleration data and the 3-axis angular rate data provide insights into the acceleration and angular rate environments of power tool **300** during the known operational states.

[0159] During active non-cutting operational state **760** and cutting operational states **770**.**1**, **770.2**, **770.3**, the vibration profile as indicated by the 3-axis acceleration data starts at approximately 0 g at trigger pull, reaches a peak of greater than approximately 3 g on at least two axes, and drops back down to approximately 0 g upon trigger release. Since the load exerted on the cutting accessory, which is often lumber material, is insignificant in comparison to the inertia of the cutting blade, no significant difference is seen on the signature of the acceleration data profile. However, the 3-axis angular rate data includes a distinct signature on one axis that aligns with user-induced actuation of the output accessory **302** of the miter saw **370** from the first position, to the second position, and back to the first position. In this example, this distinct signature can be seen on the 1.sup.nd axis angular rate data **706**, though it should be understood that depending on the orientation of the auxiliary wireless device **150**, this signature might be seen on other axes or on more than a single axis. As will be discussed in detail later, controller **160** can be configured to detect this signature on the angular rate data and detect a cutting operation accordingly.

[0160] FIG. **7**C depicts IMU sensor data plots **700**, **705** for power tool **300** during operation of the tool in the active non-cutting operational state, in accordance with embodiments of the present disclosure.

[0161] IMU sensor data plot **700** presents 3-axis acceleration data (g) over active non-cutting operational state **760** including 1.sup.st axis acceleration data **701**, 2.sup.nd axis acceleration data **702**, and 3.sup.rd axis acceleration data **703**. IMU sensor data plot **705** presents 3-axis angular rate data (degrees/sec) over active non-cutting operational state **760** including 1.sup.st axis angular rate data **706**, 2.sup.nd axis angular rate data **707**, and 3.sup.rd axis angular rate data **708**.

[0162] An example partial active non-cutting operational state window **762** (over about 0.10 seconds) is also identified to provide a zoomed-in and detailed view of the IMU sensor data plot in the active non-cutting operational state in the next figure (FIG. **7**D). As shown here, during active non-cutting operational state **760**, the peak absolute value of at least two axes of the acceleration data is greater than approximately 4 g over a 50 ms window. The 3-axis angular rate data similarly exhibits a peak absolute value of greater than 500 degrees/sec on at least one axes. Controller **160** may determine the trigger pull and release events based on one or both of the acceleration and angular rate data. However, the angular rate data does not exhibit a movement signature association with downward and upward movement of the output accessory **302** of the miter saw **370** from the first position, to the second position, and back to the first position. Thus, controller **160** does not detect a cut having been performed during this operational state.

[0163] FIG. **7**D depicts IMU sensor data plots **700**, **705** for power tool **300** during operation of the tool in the partial active non-cutting operational state within the window **762**, in accordance with embodiments of the present disclosure.

[0164] IMU sensor data plot **700** individually presents 3-axis acceleration data (g) over partial active non-cutting operational state window **762** including 1.sup.st axis acceleration data **701**, 2.sup.nd axis acceleration data **702**, and 3.sup.rd axis acceleration data **703**. IMU sensor data plot **705** individually presents 3-axis angular rate data (degrees/sec) over partial active non-cutting operational state window **762** including 1.sup.st axis angular rate data **706**, 2.sup.nd axis angular rate data **707**, and 3.sup.rd axis angular rate data **708**. Filtering and processing the 3-axis acceleration data indicates sinusoidal behavior with a frequency (370 Hz) that aligns with an unloaded output shaft speed (22,000 rpm). Furthermore, the 3-axis angular rate data includes sinusoidal waveforms visible on all three axes with a frequency (370 Hz) that aligns with an unloaded output shaft speed (22,000 rpm). This is best shown on the 2.sup.nd axis angular rate data **707**. Controller **160** may use this information to estimate the output speed of the miter saw. In addition, this information may be used, alone or in combination with the accelerometer and gyroscope signatures during active non-cutting operational state **760** and/or the cutting operational states **770.1**, **770.2**, **770.3**, to identify the type of power tool to which the auxiliary wireless device **150** is coupled.

[0165] FIG. **7**E depicts IMU sensor data plots **700**, **705** for power tool **300** during the cutting operational state **770.1**, in accordance with embodiments of the present disclosure. In this figure,

acceleration data **601**, **602**, **603** are overlapped on a first plot and angular rate data **606**, **607**, **608** are overlapped on a second plot.
[0166] FIG. **7**F depicts IMU sensor data plots **700**, **705** for power tool **300** during the cutting operational state **770.1**, in accordance with embodiments of the present disclosure. Here, acceleration data **701**, **702**, **703** are shown on three discrete plot lines and angular rate data **706**, **707**, **708** are shown on three discrete plot lines.
[0167] IMU sensor data plot **700** individually presents 3-axis acceleration data (g) over loaded operational state **770.1** including 1.sup.st axis acceleration data **701**, 2.sup.nd axis acceleration data **702**, and 3.sup.rd axis acceleration data **703**. IMU sensor data plot **705** individually presents 3-axis angular rate data (degrees/sec) over loaded operational state **770.1** including 1.sup.st axis angular rate data **706**, 2.sup.nd axis angular rate data **707**, and 3.sup.rd axis angular rate data **708**. As previously discussed, the 1.sup.st axis angular rate data **706** has a distinct rotational signature that aligns with user-induced rotation of the miter saw **370** from the first position, to the second position, and back to the first position. The details of this signature are discussed below in detail.
[0168] FIG. **7**G depicts IMU sensor data plot **705** for power tool **300** during the cutting operational state **770.1**, in accordance with embodiments of the present disclosure.
[0169] IMU sensor data plot **705** individually presents 1.sup.st axis angular rate data **706** (degrees/sec) over cutting operational state **770.1**. Trigger **311** is activated at the beginning of cutting operational state **770.1**. During zone **770.1**A, miter saw **370** positively rotates about pivot axis **374** at a certain rate and the pivoting motion slows down as output accessory **302** (cutting blade) approaches the workpiece. This is a transition from the first position to the second position. During zone **770.1**B, miter saw **370** positively rotates about pivot axis **374** at a slow rate while material is being cut and removed from the workpiece. During zone **770.1**C, miter saw **370** positively rotates about pivot axis **374** at a faster rate for a short duration as output accessory **302** briefly over-travels after the cut is complete. During zone **770.1**D, miter saw **370** negatively rotates about pivot axis **374** at a certain rate as the user pulls miter saw **370** towards the second position. During zone **770.1**E, miter saw **370** is stationary while trigger **311** is released and the electric motor and output accessory **302** coast down or brake to a stop.
[0170] Controller **160** may be configured to detect a cutting operation based on at least detection of one or more of zones **770.1**A to **770.1**E in the angular rate data during an operation of miter saw **370**. Controller **160** may further be configured to detect an abnormality in a cutting operation based on at least one of zones **770.1**A to **770.1**E not conforming to the prescribed signature. For example, if the signature of zone **770.1**C is not observed during a cutting operation, controller **160** may determine that the cut was not made all the way through. Similarly, if miter saw **370** does not return to its original position immediately after a cut, controller **160** may determine a mechanical problem with the miter saw.
[0171] Controller **160** may also be configured to detect the size of the material being cut based on the travel distance of the output accessory **302**. This may be determined based on, e.g., the peak value of the angular rate data in zones **770.1**B and/or **770.1**D, which may be greater for a larger workpiece (e.g., a 4×4 pressure treated lumber) than a smaller workpiece (e.g., 2×4 lumber).
[0172] Controller **160** may also be configured to determine the health of the cutting blade based on the IMU data. For example, if the acceleration data exhibits too much vibration during a cutting operation, or if the slope of the angular rate distinct rotational signature is too slow during cutting, controller **160** may determine that the blade is worn out and requires replacement.
[0173] Any of the above information may be communicated wirelessly by controller **160**.
[0174] Generally, determining power tool operational information may be accomplished using rules-based techniques and/or ML-based techniques. FIGS. **8**A to **8**D depict rules-based techniques for determining power tool operational information, while FIGS. **9**A to **9**E depict ML-based techniques for determining power tool operational information.
[0175] FIGS. **8**A to **8**D depict flow charts illustrating rules-based functionality associated with

IMU **168** and auxiliary wireless device **150** for determining power tool operational information, in accordance with embodiments of the present disclosure.

[0176] FIG. **8**A depicts flow chart **800** illustrating functionality associated with IMU **168** and auxiliary wireless device **150** for determining loaded operational time and cumulative loaded operational time for a power tool, in accordance with embodiments of the present disclosure.

[0177] As described above, auxiliary wireless device **150** may be mounted within a pocket of the power tool housing (such as pocket **240**, etc.) or within an auxiliary housing mounted to the power tool housing (such as auxiliary housing **140**, etc.). Other mounting configurations for auxiliary wireless device **150** are also supported.

[0178] Generally, controller **160** may determine power tool information continuously (such as executing a continuous or endless processing loop), periodically (such as every 1 second, 5 seconds, every 10 seconds, etc.), based on a user-defined schedule communicated to auxiliary wireless device **150** over network **410** from tool monitoring device **420** or tool monitoring system **430**, in response to an event (such as activation or deactivation of trigger **111**, **211**, **311**, etc.), etc. Similarly, IMU **168** may output IMU sensor data continuously, periodically, in response to a request received from controller **160**, etc.

[0179] In certain embodiments, the microcontroller or microprocessor of IMU **168** may be configured to perform the functionality described for controller **160**.

[0180] At **810**, IMU **168** outputs IMU sensor data that includes at least one of 3-axis acceleration data and 3-axis angular rate data.

[0181] As discussed above, controller **160** may be configured to determine power tool information based on both 3-axis acceleration data and 3-axis angular rate data, or, alternatively, based on either 3-axis acceleration data or 3-axis angular rate data. Accordingly, IMU **168** may be configured to output IMU sensor data that includes 3-axis acceleration data and 3-axis angular rate data to controller **160**. Alternatively, IMU **168** may be configured to output IMU sensor data that includes either 3-axis acceleration data or 3-axis angular rate data based on the processing methodology of controller **160**.

[0182] At **820**, controller **160** determines a loaded operational time of power tool **400** over a time period based on the IMU sensor data.

[0183] Generally, controller **160** processes the 3-axis angular rate data and/or the 3-axis angular rate data over the time period to determine the operational state and operational time of power tool **400** during that time period. The time period may be less than 1 second in order to capture frequent power tool activations and loadings of shorter durations. Conversely, the time period may be longer than **1** second to capture infrequent power tool activations and loadings of longer durations. Generally, the time period may accommodate activation and loading events and durations of those power tools of interest.

[0184] In certain embodiments, controller **160** may determine a loaded operational time of the power tool over the time period based on 3-axis acceleration data. Controller **160** determines, based on the 3-axis acceleration data, a peak absolute acceleration (PAA) for each axis over the time period, and then compares the PAA for each axis to a first acceleration threshold (such as 2 g, 3 g, 6 g, etc.). When the PAA for at least two axes are greater than the first acceleration threshold, controller **160** sets the loaded operational time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the loaded operational state during the time window. Conversely, when the PAA for at least two axes are not greater than the first acceleration threshold, controller **160** sets the loaded operational time of the power tool to zero. In other words, the power tool was not in a loaded operational state during the time window.

[0185] In other embodiments, controller **160** may determine an APAA for all 3 axes by summing the PAA for each axis over the time period. Controller **160** may then compare the APAA to an aggregate acceleration threshold that is greater than the first acceleration threshold. When the APAA is greater than the aggregate acceleration threshold, controller **160** sets the loaded operational time of the power tool to the time period (such as 1 second, etc.). Conversely, when the APAA is not greater than the aggregate acceleration threshold, controller **160** sets the loaded operational time of the power tool to zero.

[0186] The first acceleration threshold may be associated with the type of power tool, and may be different for different types of power tools. In certain embodiments, controller **160** may determine the type of power tool from IMU sensor data acquired after auxiliary wireless device **150** has been mounted to the power tool (FIG. **10**). In other embodiments, controller **160** may receive information indicative of the type of power tool from tool monitoring device **420** (over network **410** or a direct Bluetooth connection), from tool monitoring system **430** (over network **410**), etc. After the type of power tool has been determined, controller **160** then determines the particular thresholds that are associated with that type of power tool, such as the first acceleration threshold described above, the second and third acceleration thresholds described below, the angular rate threshold described below, as well as the first and second frequencies described below, etc.

[0187] In certain embodiments, controller **160** may determine a loaded operational time of the power tool over a time period based on **3**-axis angular rate data. Controller **160** determines, based on the 3-axis angular rate data, a peak absolute angular rate (PAAR) for each axis over the time period, and then compares the PAAR for each axis to an angular rate threshold (such as 0.2 degrees/sec, etc.). When the PAAR for at least one axis is greater than the angular rate threshold and the 3-axis angular rate data for at least one axis is sinusoidal with the angular rate frequency, controller **160** sets the loaded operational time of the power tool to the time period (such as 1 second). In other words, the power tool was in the loaded operational state during the time window. Conversely, when the PAAR for at least one axis is less than the angular rate threshold and the 3-axis angular rate data for at least one axis is not sinusoidal with the angular rate frequency, controller **160** sets the loaded operational time of the power tool to zero. In other words, the power tool was not in a loaded operational state during the time window. The angular rate frequency is related to user-induced movement of the power tool, and may be between 1 Hz and 5 Hz.

[0188] In other embodiments, controller **160** may determine an APAAR for all 3 axes by summing the PAAR for each axis over the time period. Controller **160** may then compare the APAAR to an aggregate angular rate threshold that is greater than the angular rate threshold. When the APAAR is greater than the aggregate angular rate threshold, controller **160** sets the loaded operational time of the power tool to the time period (such as 1 second, etc.). Conversely, when the APAAR is not greater than the aggregate angular rate threshold, controller **160** sets the loaded operational time of the power tool to zero.

[0189] In certain embodiments, controller **160** may determine a loaded operational time of the power tool over a time period based on 3-axis acceleration data and 3-axis angular rate data by combining the acceleration thresholds, angular rate threshold, angular rate frequencies and comparison tests.

[0190] At **830**, controller **160** may determine a cumulative loaded operational time of the power tool based on loaded operational times within a cumulative time period.

[0191] For example, at **830**, controller **160** repeats the determination of the loaded operational time (at **820**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of loaded operational times to determine the cumulative loaded operational time. In certain embodiments, the value of the cumulative time period may be a multiple of the value of the time period. In one example, the time period may be 1 second, the cumulative time period may be 60 seconds, and the power tool was activated in a loaded condition during 20 time periods (i.e., loaded operational state). In this example, each loaded operational time is 1 second, and the cumulative loaded operational time is 20 seconds.

[0192] At **840**, controller **160** may send the cumulative loaded operational time to WCU **164** for transmission to a remote device.

[0193] WCU **164** may send a message over network **410** (or a direct Bluetooth connection) to tool monitoring device **420**. Similarly, WCU **164** may send a message over network **410** to tool monitoring system **430**, which may provide a power tool inventory and operational database for security, maintenance, and other purposes.

[0194] FIG. **8**B depicts flow chart **802** illustrating functionality associated with auxiliary wireless device **150** for determining unloaded operational time, non-operating movement time and rest time for a power tool, in accordance with embodiments of the present disclosure.

[0195] After controller **160** determines the loaded operational time of the power tool for a time period (at **820** in FIG. **8**A), flow may proceed to **822** through “A.”

[0196] At **822**, controller **160** may determine an unloaded operational time of the power tool over the time period.

[0197] In certain embodiments, controller **160** may determine the unloaded operational time of the power tool over the time period based on **3-**axis acceleration data. Controller **160** compares the PAA for each axis to a second acceleration threshold (such as 2 g, 4 g, etc.) that is less than the first acceleration threshold. When the PAA for at least two axes are less than the first acceleration threshold and greater than the second acceleration threshold, controller **160** sets the unloaded operational time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the unloaded operational state during the time window. Conversely, when the PAA for at least two axes are not less than the first acceleration threshold and greater than the second acceleration threshold, controller **160** sets the unloaded operational time of the power tool to zero. In other words, the power tool was not in an unloaded operational state during the time window. The second acceleration threshold may be associated with the type of power tool, and may be different for different types of power tools, as discussed above.

[0198] In certain embodiments, controller **160** may determine the unloaded operational time of the power tool over the time period based on 3-axis angular rate data. Controller **160** compares the PAAR for each axis to the angular rate threshold. When the PAAR for at least one axis is greater than the angular rate threshold and the 3-axis angular rate data for at least one axis is sinusoidal with a second angular rate frequency, controller **160** sets the loaded operational time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the unloaded operational state during the time window. Conversely, when the PAAR for at least one axis is less than the angular rate threshold and the 3-axis angular rate data for at least one axis is not sinusoidal with the angular rate frequency, controller **160** sets the loaded operational time of the power tool to zero. In other words, the power tool was not in a loaded operational state during the time window. The angular rate frequency is related to user-induced movement of the power tool, and may be between 1 Hz and 5 Hz.

[0199] In certain embodiments, controller **160** may determine an unloaded operational time of the power tool over a time period based on 3-axis acceleration data and 3-axis angular rate data by combining the acceleration thresholds, angular rate threshold, angular rate frequencies and comparison tests.

[0200] At **824**, controller **160** may determine a non-operating movement time of the power tool over the time period.

[0201] In certain embodiments, controller **160** compares the PAA for each axis to a third acceleration threshold (such as 1 g, 2 g, etc.) that is less than the second acceleration threshold. When the PAA for at least one axis is less than the second acceleration threshold and greater than the third acceleration threshold, controller **160** sets the non-operating movement time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the non-operating movement state during the time window. Conversely, when the PAA for at least one axis is not less than the second acceleration threshold and greater than the third acceleration threshold, controller **160** sets the non-operating movement time of the power tool to zero. In other words, the power tool was not in a non-operating movement state during the time window. The third acceleration threshold may be associated with the type of power tool, and may be different for

different types of power tools, as discussed above.
[0202] At **826**, controller **160** may determine a rest time of the power tool over the time period.
[0203] In certain embodiments, controller **160** compares the PAA for each axis to the third acceleration threshold. When the PAA for each axis are less than the third acceleration threshold, controller **160** sets the rest time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the rest state during the time window.
[0204] Flow may then return to **830** through “A” (FIG. **8**A).
[0205] FIG. **8**C depicts flow chart **804** illustrating functionality associated with auxiliary wireless device **150** for determining cumulative unloaded operational time, cumulative non-operating movement time and cumulative rest time for a power tool, in accordance with embodiments of the present disclosure.
[0206] After controller **160** determines a cumulative loaded operational time of the power tool based on loaded operational times within a cumulative time period (at **830** in FIG. **8**A), flow may proceed to **832** through “B.”
[0207] At **832**, controller **160** may determine a cumulative unloaded operational time of the power tool based on unloaded operational times within the cumulative time period.
[0208] Controller **160** repeats the determination of the unloaded operational time (at **822**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of unloaded operational times to determine the cumulative unloaded operational time.
[0209] At **834**, controller **160** may determine a cumulative non-operating movement time of the power tool based on non-operating movement times within the cumulative time period.
[0210] Controller **160** repeats the determination of the non-operating movement time (at **824**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of non-operating movement times to determine the cumulative non-operating movement time.
[0211] At **834**, controller **160** may determine a cumulative rest time of the power tool based on rest times within the cumulative time period.
[0212] Controller **160** repeats the determination of the rest time (at **826**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of rest times to determine the cumulative rest time.
[0213] Flow may then return to **840** through “B” (FIG. **8**A).
[0214] FIG. **8**D depicts flow chart **806** illustrating functionality associated with auxiliary wireless device **150** for sending cumulative unloaded operational time, cumulative non-operating movement time and cumulative rest time for a power tool to a remote device, in accordance with embodiments of the present disclosure.
[0215] After controller **160** sends the cumulative loaded operational time to WCU **164** for transmission to a remote device (at **840** in FIG. **8**A), flow may proceed to **842** through “C.”
[0216] At **842**, controller **160** may send the cumulative unloaded operational time to the WCU for transmission to the remote device.
[0217] At **844**, controller **160** may send the cumulative non-operating movement time to the WCU for transmission to the remote device.
[0218] At **846**, controller **160** may send the cumulative rest time to the WCU for transmission to the remote device.
[0219] FIGS. **9**A to **9**D depict flow charts illustrating ML-based functionality associated with IMU **168** and auxiliary wireless device **150** for determining power tool operational information, in accordance with embodiments of the present disclosure.
[0220] FIG. **9**A depicts flow chart **900** illustrating functionality associated with IMU **168** and auxiliary wireless device **150** for determining loaded operational time and cumulative loaded operational time for a power tool, in accordance with embodiments of the present disclosure.

[0221] At step **910**, IMU **168** outputs IMU sensor data that includes at least one of 3-axis acceleration data and 3-axis angular rate data (similar to **810**).
[0222] At step **920**, controller **160** executes an ML model to determine a loaded operational time of the power tool over a time period based on the IMU sensor data.
[0223] In certain embodiments, controller **160** provides 3-axis acceleration data and/or 3-axis angular rate data over the time period to the ML model. In one example, the ML model is a recursive neural network (RNN) that has been trained to take, as input, time series 3-axis acceleration data and/or input time series 3-axis angular rate data, and then predict the loaded operational state of the power tool based on the 3-axis acceleration data and/or the 3-axis angular rate data. The ML model may provide a simple binary classification, such as true (or 1) for a loaded operational state, and false (or 0) for any other operational state. When the prediction is true, controller **160** sets the loaded operational time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the loaded operational state during the time window. Conversely, when the prediction is false, controller **160** sets the loaded operational time of the power tool to zero. In other words, the power tool was not in a loaded operational state during the time window.
[0224] In certain embodiments, the microcontroller or microprocessor of IMU **168** may execute the ML model, and provide the predicted loaded operational state to controller **160**.
[0225] At step **930**, controller **160** may determine a cumulative loaded operational time of the power tool based on loaded operational times within a cumulative time period.
[0226] Controller **160** repeats the determination of the loaded operational time (at **920**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of loaded operational times to determine the cumulative loaded operational time. In certain embodiments, the value of the cumulative time period may be a multiple of the value of the time period. In one example, the time period may be 1 second, the cumulative time period may be 60 seconds, and the power tool was activated in a loaded condition during 20 time periods (i.e., loaded operational state). In this example, each loaded operational time is 1 second, and the cumulative loaded operational time is 20 seconds.
[0227] At step **940**, controller **160** may send the cumulative loaded operational time to WCU **164** for transmission to a remote device.
[0228] WCU **164** may send a message over network **410** (or, e.g., a direct Bluetooth connection) to tool monitoring device **420**. Similarly, WCU **164** may send a message over network **410** to tool monitoring system **430**, which may provide a power tool inventory and operational database for security, maintenance, and other purposes.
[0229] FIG. **9**B depicts flow chart **902** illustrating functionality associated with auxiliary wireless device **150** for determining unloaded operational time, non-operating movement time and rest time for a power tool, in accordance with embodiments of the present disclosure.
[0230] After controller **160** determines the loaded operational time of power tool **400** for a time period (at **920** in FIG. **9**A), flow may proceed to **922** through “D.”
[0231] At step **922**, controller **160** may determine an unloaded operational time of the power tool over the time period.
[0232] In another example, an ML model (e.g., an RNN) is trained to take, as input, time series 3-axis acceleration data and/or input time series 3-axis angular rate data, and then predict the unloaded operational state of the power tool based on the 3-axis acceleration data and/or the 3-axis angular rate data. The ML model may provide a simple binary classification, such as true (or 1) for an unloaded operational state, and false (or 0) for any other operational state. When the prediction is true, controller **160** sets the unloaded operational time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the unloaded operational state during the time window. Conversely, when the prediction is false, controller **160** sets the unloaded operational time of the power tool to zero. In other words, the power tool was not in an unloaded operational

state during the time window.

[0233] In certain embodiments, the microcontroller or microprocessor of IMU **168** may execute the ML model, and provide the predicted unloaded operational state to controller **160**.

[0234] At step **924**, controller **160** may determine a non-operating movement time of the power tool over the time period.

[0235] In another example, an ML model (such as an RNN, etc.) is trained to input time series 3-axis acceleration data and/or input time series 3-axis angular rate data, and then predict the non-operating movement state of the power tool based on the 3-axis acceleration data and/or the 3-axis angular rate data. The RNN may provide a simple binary classification, such as true (or 1) for a non-operating movement state, and false (or 0) for any other operational state. When the prediction is true, controller **160** sets the non-operating movement time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the non-operating movement state during the time window. Conversely, when the prediction is false, controller **160** sets the non-operating movement time of the power tool to zero. In other words, the power tool was not in a non-operating movement state during the time window.

[0236] In certain embodiments, the microcontroller or microprocessor of IMU **168** may execute the ML model, and provide the predicted non-operating movement state to controller **160**.

[0237] At step **926**, controller **160** may determine a rest time of the power tool over the time period.

[0238] In certain embodiments, steps **920**, **922**, **924**, and **926** may be collapsed into a single execution of ML model, which will determine whether the power tool was in the loaded operational state, the unloaded operational state, the non-operating movement state, or the rest state during each time window. In one example, an ML model may provide a class prediction, which would include a loaded class, an unloaded class, a movement class, and a rest class.

[0239] In another example, the ML model is an RNN that has been trained to input time series 3-axis acceleration data and/or input time series 3-axis angular rate data, and then predict the rest state of the power tool based on the 3-axis acceleration data and/or the 3-axis angular rate data. The ML model may provide a simple binary classification, such as true (or 1) for a rest state, and false (or 0) for any other operational state. When the prediction is true, controller **160** sets the rest time of the power tool to the time period (such as 1 second, etc.). In other words, the power tool was in the rest state during the time window. Conversely, when the prediction is false, controller **160** sets the rest time of the power tool to zero. In other words, the power tool was not in a rest state during the time window.

[0240] In certain embodiments, the microcontroller or microprocessor of IMU **168** may execute the ML model, and provide the predicted rest state to controller **160**.

[0241] Flow may then return to step **930** through "D" (FIG. **9**A).

[0242] FIG. **9**C depicts flow chart **904** illustrating functionality associated with auxiliary wireless device **150** for determining cumulative unloaded operational time, cumulative non-operating movement time and cumulative rest time for a power tool, in accordance with embodiments of the present disclosure.

[0243] After controller **160** determines a cumulative loaded operational time of the power tool based on loaded operational times within a cumulative time period (at **930** in FIG. **9**A), flow may proceed to step **932** through "E."

[0244] At step **932**, controller **160** may determine a cumulative unloaded operational time of the power tool based on unloaded operational times within the cumulative time period.

[0245] Controller **160** repeats the determination of the unloaded operational time (at **922**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of unloaded operational times to determine the cumulative unloaded operational time.

[0246] At step **934**, controller **160** may determine a cumulative non-operating movement time of the power tool based on non-operating movement times within the cumulative time period.

[0247] Controller **160** repeats the determination of the non-operating movement time (at **924**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of non-operating movement times to determine the cumulative non-operating movement time.

[0248] At step **936**, controller **160** may determine a cumulative rest time of the power tool based on rest times within the cumulative time period.

[0249] Controller **160** repeats the determination of the rest time (at **926**) for the number of time periods that are within the cumulative time period. Controller **160** then accumulates (sums) the number of rest times to determine the cumulative rest time.

[0250] Flow may then return to step **940** through "E" (FIG. **9**A).

[0251] FIG. **9**D depicts flow chart **906** illustrating functionality associated with auxiliary wireless device **150** for sending cumulative unloaded operational time, cumulative non-operating movement time and cumulative rest time for a power tool to a remote device, in accordance with embodiments of the present disclosure.

[0252] After controller **160** sends the cumulative loaded operational time to WCU **164** for transmission to a remote device (at **940** in FIG. **9**A), flow may proceed to **942** through "F."

[0253] At step **942**, controller **160** may send the cumulative unloaded operational time to the WCU for transmission to the remote device.

[0254] At step **944**, controller **160** may send the cumulative non-operating movement time to the WCU for transmission to the remote device.

[0255] At step **946**, controller **160** may send the cumulative rest time to the WCU for transmission to the remote device.

[0256] FIG. **9**E depicts flow chart **908** illustrating functionality associated with training an ML model to predict power tool operational states, in accordance with embodiments of the present disclosure.

[0257] At step **950**, model training system **440** generates ML model training data based on historical IMU sensor data that were acquired for power tools that were operating in various conditions, such as a loaded operational state, an unloaded operational state, a non-operating movement state, and a rest state. More particularly, the historical IMU sensor data for each power tool includes 3-axis acceleration data and 3-axis angular rate data that were acquired when the power tool was operating in each operational condition. A different label is associated with the data acquired during each operational condition to identify the operational state for training purposes.

[0258] At **960**, model training system **440** trains the ML model to determine power tool operational states based on a training portion of the ML model training data. In certain embodiments, an ML model is trained to predict a single operational state, while in other embodiments, the ML model is trained to predict a class of operational states (such as a loaded class, an unloaded class, a movement class and a rest class).

[0259] In certain embodiments, the ML model training data includes a number of data records for each power tool. Each data record may include information associated with a single operational state for the power tool, such as 3-axis acceleration data and 3-axis angular rate data that were acquired during that operational state, a label that identifies that operational state, etc.

[0260] At **970**, model training system **440** validates the ML model to determine power tool operational states based on a validation portion of the ML model training data that is different than the training portion of the ML model training data. Validating the ML model includes evaluating the performance of the ML model using different training data, and then tuning the ML model parameters to produce the best performance.

[0261] In certain embodiments, the ML model may be trained and validated based on historical IMU sensor data for a particular type of power tool. The ML model would then be specific to that particular type of power tool. In other embodiments, the ML model may be trained (and retrained) based on historical IMU sensor data for a number of different types of power tools. The ML model would then be generic with respect to the type of power tool.

[0262] FIG. **10** depicts flow chart **1000** illustrating functionality associated with auxiliary wireless device **150** for determining power tool operational parameters, in accordance with embodiments of the present disclosure.

[0263] At **1010**, IMU **168** outputs IMU sensor data that includes at least one of 3-axis acceleration data or 3-axis angular rate data.

[0264] At **1020**, controller **160** determines one or more operational parameters of power tool **400** over a time period based on the IMU sensor data. The one or more operational parameters may include the type of power tool, the type of operation being performed by the power tool, the type of output accessory mounted to the power tool, etc. The techniques for determining the one or more operational parameters may include the techniques described above for determining the operational state of the power tool.

[0265] Generally, determining the unloaded operational state for power tool **100** (impact wrench) is different than determining the unloaded operational state for power tool **200** (angle grinder), which is different than determining the unloaded operational state for power tool **300** (miter saw). Similarly, determining the loaded operational state for power tool **100** (impact wrench) is different than determining the loaded operational state for power tool **200** (angle grinder), which is different than determining the loaded operational state for power tool **300** (miter saw). Acceleration data may be preferred for identifying impact tools, angular rate data and associated frequencies may be preferred for identifying angle grinders, acceleration and angular rate data may be preferred for identifying miter saws, etc. Accordingly, the type of power tool may be determined by processing the IMU sensor data according to the rule-based techniques described above to determine the best match for the unloaded and loaded operational states.

[0266] For example, transforming the 3-axis angular rate data for a power tool operating in an unloaded operational state from the time domain into the frequency domain may identify a sinusoidal waveform that has a frequency associated with the "no load" speed of the power tool. Because the no load speed for the impact wrench (˜2,400 rpm), the angle grinder (˜7,800 rpm), and the miter saw (˜22,000 rpm) are sufficiently distinct, the type of power tool may be identified from the frequency domain data.

[0267] In other examples, the 3-axis acceleration data for the loaded impact wrench is significantly higher than the 3-axis acceleration data for the loaded angle grinder and the loaded the miter saw, and may be used to identify the loaded operational state for the impact wrench. Transforming the 3-axis angular rate data from the time domain into the frequency domain may identify a sinusoidal waveform that has a frequency associated with a user-induced rhythmic oscillation (such as a grinding or polishing motion) that may be used to identify the loaded operational state for the angle grinder. A combination of 3-axis acceleration data and 3-axis angular rate data may be used to identify a miter saw when the PAA of at least two axes are greater than 3 g and the 3-axis angular rate data depicts a waveform that has a profile associated with the user-induced transition depicted in FIG. **7**G.

[0268] At **1030**, controller **160** may send the one or more operational parameters to WCU **164** for transmission to a remote device.

[0269] In certain embodiments, the IMU sensor data includes at least one of 3-axis acceleration data when the power tool is activated in a loaded condition, 3-axis angular rate data when the power tool is activated in the loaded condition, 3-axis acceleration data when the power tool is activated in an unloaded condition, and 3-axis angular rate data when the power tool is activated in the unloaded condition.

[0270] The power tool may be any type of cordless or corded, handheld or stationary power tool, including but not limited to, drills, hammer drills, drivers, impact drivers, impact wrenches, angle grinders, die grinders, straight grinders, polishers, routers, planers, circular saws, miter saws, reciprocating saws, rotary hammers, etc. The type of operation being performed by the power tool may include drilling, driving, impact driving, heavy grinding, light grinding, polishing, removing material, cutting, etc. The type of accessory mounted to the power tool may include a drill bit, a driver bit, a socket, a grinding wheel, a cutting wheel, a saw blade, etc.

[0271] In certain embodiments, controller **160** may be configured to identify the type of power tool to which auxiliary wireless device **150** is coupled based on IMU data. For example, the profile and behavior of the data corresponding to the loaded operation of an impact wrench is different from the loaded operation of a grinder and a miter saw. Similarly, the profile and behavior of the data corresponding to the loaded operation of a grinder is different from the loaded operation of a miter saw. For certain tools, the profile and behavior of the data corresponding to the unloaded operation of the power tool may also uniquely identify the tool, or may identify a category to which the tool belongs, such as drills and drivers (including impact wrenches), grinders (including angle grinders), power saws (including miter saws), etc.

[0272] More particularly, IMU sensor data plots **500**, **505** exhibit unique characteristics for an impact wrench that controller **160** may use to identify impact wrenches from other power tools.

[0273] In this example, during loaded operational state **570**, the peak absolute value of all axes of the 3-axis acceleration data is greater than 6 g (over a 50 ms window). Filtering and processing the 3-axis acceleration data exposes sinusoidal waveforms with a frequency (56 Hz) that aligns with the impact rate of the impactor assembly (˜3,400 rpm). Intermediate, smaller peaks represent hammer rebound of the impactor assembly. During unloaded operational state **560**, filtering and processing the 3-axis angular rate data exposes a sinusoidal waveform on (at least) one axis that aligns with the no load speed (˜2,400 rpm).

[0274] IMU sensor data plots **600**, **605** also exhibit unique characteristics for an angle grinder that may be used to identify angle grinders from other power tools, as well as certain output accessories for angle grinders.

[0275] In this example, during heavy loaded operational state **670**.**1**, the peak absolute value of at least 2 axes of the acceleration data is greater than 12 g (over a 50 ms window). Filtering and processing the 3-axis acceleration data exposes sinusoidal waveforms with a frequency that aligns with unloaded output shaft speed (˜7,800 rpm). The 3-axis angular rate data may include a similar frequency component, and the peak absolute value of at least one axis of the angular rate data exceeds 180 degrees/sec. Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (4 Hz) that aligns with user-induced movement commonly associated with a heavy grinding operation. Generally, the user-induced movement of an angle grinder (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz, which may be exhibited by other type of power tools, such as polishers, etc.

[0276] In another example, during light loaded operational state **670**.**2**, the peak absolute value of at least 2 axes of the acceleration data is greater than 8 g (over a 50 ms window). Filtering and processing the 3-axis acceleration data exposes sinusoidal waveforms with a frequency that aligns with unloaded output shaft speed (˜7,800 rpm). The 3-axis angular rate data may include a similar frequency component, and the peak absolute value of at least one axis of the angular rate data exceeds 160 degrees/sec. Overall, the acceleration data and the angular rate data may include similar frequencies exhibited during the loaded operational state **670**.**1**, but with smaller overall amplitudes. Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (4 Hz) that aligns with user-induced movement commonly associated with a light grinding operation. Generally, the user-induced movement of an angle grinder (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz, which may be exhibited by other types of power tools, such as polishers, etc.

[0277] In yet another example, during loaded operational state **670**.**3** (using an alternative grinding disc), the peak absolute value of at least 2 axes of the acceleration data is greater than 4 g but smaller than 8 g (over a 50 ms window). Filtering and processing the 3-axis acceleration data exposes sinusoidal waveforms with a frequency that aligns with unloaded output shaft speed (˜7,800 rpm). The 3-axis angular rate data may include a similar frequency component, and the peak absolute value of at least one axis of the angular rate data exceeds 160 degrees/sec. Overall, the acceleration data and the angular rate data may include similar frequencies exhibited during the loaded operational state **670**.**1**, **670**.**2**, but with smaller overall amplitudes. Additionally, the 3-axis angular rate data exhibits a sinusoidal pattern visible on at least two axes with a second frequency component (3 Hz) that aligns with user-induced movement. Generally, the user-induced movement of an angle grinder (such as rhythmic tool oscillations) may be from 1 Hz to 5 Hz, which may be exhibited by other types of power tools, such as polishers, etc.

[0278] During unloaded operational state **660**, filtering and processing the 3-axis angular rate data exposes a sinusoidal waveform on (at least) one axis that aligns with the no load speed (˜7,800 rpm).

[0279] IMU sensor data plots **700**, **705** also exhibit unique characteristics for a miter saw that may be used to distinguish a miter saw from other power tools.

[0280] In one example, during loaded operational state **770**.**1**, the peak absolute value of at least 2 axes of the acceleration data reaches a peak of greater than approximately 3 g (while trigger **311** is engaged). Additionally, the cutting operations exhibit a predictable positive/negative spike pattern in at least one axis of the 3-axis angular rate data. As discussed above, the cutting operation during loaded operational state **770**.**1** may be divided into zones **770**.**1**A, **770**.**1**B, **770**.**1**C, **770**.**1**D, **770**.**1**E. During zone **770**.**1**A, miter saw **370** positively rotates about pivot axis **374** at a certain rate and the pivoting motion slows down as output accessory **302** (cutting blade) approaches the work piece. This is a transition from the first position to the second position. During zone **770**.**1**B, miter saw **370** positively rotates about pivot axis **374** at a slow rate while material is being cut and removed from the work piece. During zone **770**.**1**C, miter saw **370** positively rotates about pivot axis **374** at a faster rate for a short duration as output accessory **302** briefly over-travels after the cut is complete. During zone **770**.**1**D, miter saw **370** negatively rotates about pivot axis **374** at a certain rate as the user pulls the miter saw towards the second position. During zone **770**.**1**E, miter saw **370** is stationary while trigger **311** is released and the electric motor and output accessory **302** coast down or brake to a stop. The positive/negative spike pattern is exposed in zone **770**.**1**C (positive spike) and zone **770**.**1**D (negative spike).

[0281] During active non-cutting operational state **760** (also known as an unloaded operational state), filtering and processing the 3-axis angular rate data exposes a sinusoidal waveform on (at least) one axis that aligns with the no load speed (˜22,000 rpm).

[0282] FIG. **11** depicts flow chart **1100** illustrating functionality associated with auxiliary wireless device **150** for determining a type of tool, in accordance with embodiments of the present disclosure.

[0283] At **1110**, controller **160** receives IMU sensor data including 3-axis acceleration data and 3-axis angular rate data.

[0284] At **1120**, controller **160** determines a type of tool based on the IMU sensor data. More particularly, controller **160** may process 3-axis acceleration data to determine the peak absolute value of all axes of the 3-axis acceleration data over a particular window of time, and then compare the peak absolute values to various thresholds, such as 3 g, 4 g, 6 g, 8 g, 12 g, etc. Controller **160** may also process the 3-axis angular rate data to identify the peak absolute value of all axes of the 3-axis angular rate data over the particular time window, and then compare the peak absolute values to various thresholds, such as 160 degrees/sec, 180 degrees/sec, etc. Additionally, controller **160** may filter and process the 3-axis angular rate data to identify sinusoidal waveforms and their respective frequencies, and then compare the frequencies to various values, thresholds, ranges, patterns, etc., such as 3 Hz, 4 Hz, 1 to 5 Hz, 56 Hz, 128 Hz, 370 Hz, positive/negative spike patterns, etc. In certain embodiments, controller **160** monitors the IMU sensor data for a predetermined amount of time (such as 10 loaded operation cycles after the initial attachment to a tool) to determine the type of tool to which it is coupled.

[0285] In one example, to determine whether the tool type is an impact wrench, controller **160** may compare the peak absolute value of all axes of the 3-axis acceleration data to several thresholds. If the peak absolute value of at least two axes of the acceleration data are less than a first acceleration threshold (e.g., 2 g), then an impact wrench tool type may not be determinable. If the peak absolute value of at least two axes of the acceleration data are greater than the first acceleration threshold (e.g., 2 g) but less than a second acceleration threshold (e.g., 6 g), then controller **160** may compare the processed **3**-axis angular rate data to determine whether a sinusoidal waveform is present on at least one axis with a frequency (e.g., 40 Hz) that aligns with an unloaded output shaft speed (e.g., 2,400 rpm). If so, the tool type may be determined to be an impact wrench. If the peak absolute value of at least two axes of the acceleration data are greater than the second acceleration threshold (e.g., 6 g), then controller **160** may inspect the processed 3-axis angular rate data to determine whether a sinusoidal waveform is present on at least one axis with a frequency (e.g., 56 Hz) that aligns with the impact rate of the impactor assembly (e.g., 3,400 rpm). If so, the tool type may be determined to be an impact wrench. Generally, the acceleration threshold may be expressed as a range of acceleration values, such as 2 g to 8 g, the unloaded output shaft speed may be expressed as a range of speeds, such as 1,800 rpm to 3,000 rpm, and the impact rate of the impactor assembly may be expressed as a range of speeds, such as 3,000 rpm to 3,720 rpm.

[0286] In another example, to determine whether the tool type is an angle grinder, controller **160** may compare the peak absolute value of all axes of the 3-axis acceleration data to a threshold. If the peak absolute value of at least two axes of the acceleration data are less than a first acceleration threshold (e.g., 4 g), then an angle grinder tool type may not be determinable. If the peak absolute value of at least two axes of the acceleration data are greater than the first acceleration threshold (e.g., 4 g), then controller **160** may compare the peak absolute value of all axes of the 3-axis angular rate data to a threshold. If the peak absolute value of at least one axis of the angular rate data exceeds **160** degrees/sec (or 180 degrees/sec), then controller **160** may analyze the processed 3-axis angular rate data to determine whether a sinusoidal waveform is present on at least one axis with a frequency (e.g., 128 Hz) that aligns with an unloaded output shaft speed (e.g., 7,800 rpm). Additionally, controller **160** may inspect the processed 3-axis angular rate data to determine whether a sinusoidal waveform is present with a low frequency component (e.g., between 1 Hz and 5 Hz, such as 3 Hz, 4 Hz, etc.) that aligns with user-induced movement commonly associated with a grinding operation. If one or more of these conditions are met, the tool type may be determined to be an angle grinder. Generally, the acceleration threshold may be expressed as a range of acceleration values, such as 2 g to 6 g, the angular rate threshold may be expressed as a range of angular rate values, such as 140 degrees/sec to 200 degrees/sec, and the unloaded output shaft speed may be expressed as a range of speeds, such as 7,200 rpm to 8,400 rpm.

[0287] In a further example, to determine whether the tool type is a cordless miter saw, controller **160** may compare the peak absolute value of all axes of the 3-axis acceleration data to a threshold. If the peak absolute values of at least two axes of the acceleration data are less than 3 g, then a cordless miter saw tool type may not be determinable. If the peak absolute value of at least two axes of the acceleration data are greater than 3 g, then controller **160** may analyze the processed 3-axis angular rate data to determine whether a sinusoidal waveform is present on at least one axis with a frequency (e.g., 370 Hz) that aligns with an unloaded output shaft speed (e.g., 22,000 rpm). Additionally, controller **160** may inspect the 3-axis angular rate data to determine whether a positive/negative spike pattern is present, for example as depicted in zone **770**.**1**C (positive spike) and zone **770**.**1**D (negative spike) of FIG. **7**G. If one or more of these conditions are met, the tool type may be determined to be a cordless miter saw. Generally, the acceleration threshold may be expressed as a range of acceleration values, such as 2 g to 6 g, and the unloaded output shaft speed may be expressed as a range of speeds, such as 21,000 rpm to 23,400 rpm.

[0288] FIG. **12** depicts flow chart **1200** illustrating functionality associated with auxiliary wireless device **150** for determining a type of output accessory, in accordance with embodiments of the present disclosure.

[0289] Generally, controller **160** may identify the type of output accessory mounted onto the power tool based on IMU sensor data. For example, certain types of angle grinder discs may be identified based on the 3-axis acceleration data and/or 3-axis angular rate data.

[0290] At **1210**, controller **160** receives IMU sensor data including 3-axis acceleration data and 3-axis angular rate data.

[0291] At **1220**, controller **160** determines a type of output accessory based on the IMU sensor data. More particularly, controller **160** may process 3-axis acceleration data to determine the peak absolute value of all axes of the 3-axis acceleration data over a particular window of time, and then compare the peak absolute values to various thresholds and ranges, such as 4 g, 8 g, 12 g, 4 g to 8 g, 8 g to 12 g, etc. to determine the type of output accessory. In the examples depicted in FIGS. **6**A to **6**J, heavy loaded operational state **670.1** and light loaded operational state **670.1** use a grinding disc, while loaded operational state **670.3** uses a flap disc. For these examples, controller **160** may determine the type of output accessory (disc) currently being used by an angle grinder by comparing the peak absolute values to a range, such as 4 g to 8 g, and a threshold, such as 8 g. If the peak absolute values are within the range, then controller **160** may determine that the type of output accessory is a flap disc, and if the peak absolute values are greater than the threshold, then controller **160** may determine that the type of output accessory is a grinding disc.

[0292] FIG. **13** depicts flow chart **1300** illustrating functionality associated with auxiliary wireless device **150** for determining a type of fault, in accordance with embodiments of the present disclosure.

[0293] At **1310**, controller **160** receives IMU sensor data including 3-axis acceleration data and 3-axis angular rate data.

[0294] At **1320**, controller **160** determines a type of fault based on the IMU sensor data. More particularly, controller **160** may process 3-axis acceleration data to determine the peak absolute value of all axes of the 3-axis acceleration data over a particular window of time, and then compare the peak absolute values to various thresholds and ranges. Controller **160** may also process the 3-axis angular rate data to identify the peak absolute value of all axes of the 3-axis angular rate data over the particular time window, and then compare the peak absolute values to various thresholds.

[0295] The type of fault may include a kickback condition, an overcurrent shutdown event, a dropped tool event, etc. For example, controller **160** may identify the kickback condition by determining that the one or more axes of the 3-axis angular rate data includes a rapid spike. For another example, controller **160** may identify the overcurrent shutdown event by determining that one or more axes of the 3-axis angular rate data exceed a high limit followed by a sudden tool shutdown (indicated by a rapid reduction in acceleration levels). For a further example, controller **160** may identify the dropped tool event by determining that the one or more axes of the **3**-axis acceleration data includes a rapid spike.

[0296] At **1320**, controller **160** sends the type of fault to WCU **164** for transmission to remote device.

[0297] FIG. **14** depicts IMU sensor data plot **1400** for auxiliary wireless device **150**, in accordance with embodiments of the present disclosure.

[0298] In certain embodiments, pocket **240** may include identification structure **242** with a number of features **244**, such as parallel, non-uniformly-spaced slots (as depicted in FIG. **14**), bumps, rumble strips, Braille-like features, etc. The insertion of auxiliary wireless device **150** into pocket **240** would cause auxiliary wireless device **150** to slide over identification structure **242** to generate a unique acceleration signature. IMU **168** would output the associated **3-**axis acceleration data to controller **160**, which would process the acceleration signature to determine the type of power tool associated with identification structure **242**.

[0299] More particularly, the characteristics of features **244** may be associated with the type of power tool, such as the number of features **244**, the depth of features **244**, the spacing between features **244**, the alignment of features **244**, etc. In certain embodiments, the features **244** may have at least two depths, and each slot depth would produce a different peak acceleration. In other embodiments, the spacing between features **244** may be non-uniform or features **244** may be non-parallel (aligned on multiple axes).

[0300] IMU sensor data plot **1400** presents **3**-axis acceleration data (g) over time (about 6 seconds) including 1.sup.st axis acceleration data **1401**, 2.sup.nd axis acceleration data **1402**, and 3.sup.rd axis acceleration data **1403**.

[0301] During first time period **1410**, auxiliary wireless device **150** is sliding over a smooth portion of pocket **240** during the initial insertion. During second time period **1420**, auxiliary wireless device **150** is sliding over identification structure **242** of pocket **240** to generate a unique 3-axis acceleration signature having 6 acceleration peaks (numbered 1 to 6). Acceleration peaks **1**, **3**, **4**, and **6** are associated with deeper, multi-layered slots, while acceleration peaks **2** and **5** are associated with narrower, single layer slots.

[0302] Example embodiments have been provided so that this disclosure will be thorough, and to fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0303] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0304] When an element or layer is referred to as being “on,” “engaged to,” “connected to,” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an clement is referred to as being “directly on,” “directly engaged to,” “directly connected to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0305] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as “first,” “second,” and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0306] Terms of degree such as “generally,” “substantially,” “approximately,” and “about” may be

used herein when describing the relative positions, sizes, dimensions, or values of various elements, components, regions, layers and/or sections. These terms mean that such relative positions, sizes, dimensions, or values are within the defined range or comparison (e.g., equal or close to equal) with sufficient precision as would be understood by one of ordinary skill in the art in the context of the various elements, components, regions, layers and/or sections being described.
[0307] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

Claims

1. An auxiliary wireless device, comprising: a body removably attachable to a housing of a power tool; a wireless communication unit (WCU), supported by the body, the WCU including a wireless transceiver; an inertial measurement unit (IMU), supported by the body, the IMU configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data; and a controller, in communication with the WCU and the IMU, the controller configured to: determine a loaded operational time of the power tool over a time period based on the IMU sensor data, determine a cumulative loaded operational time of the power tool based on loaded operational times within a cumulative time period, and send the cumulative loaded operational time to the WCU for transmission to a remote device, wherein the power tool is activated in a loaded condition during the loaded operational time.
2. The auxiliary wireless device of claim 1, wherein: determine the loaded operational time includes: determine, based on the 3-axis acceleration data, a peak absolute acceleration (PAA) for each axis over the time period; compare the PAA for each axis to a first acceleration threshold; and set the loaded operational time of the power tool to the time period when the PAA for at least two axes are greater than the first acceleration threshold.
3. The auxiliary wireless device of claim 2, wherein: the controller is further configured to: determine an unloaded operational time of the power tool over the time period, including: compare the PAA for each axis to a second acceleration threshold that is less than the first acceleration threshold, and set an unloaded operational time of the power tool to the time period when the PAA for at least two axes are less than the first acceleration threshold and greater than the second acceleration threshold, determine a cumulative unloaded operational time of the power tool based on unloaded operational times within the cumulative time period, and send the cumulative unloaded operational time to the WCU for transmission to the remote device; and the power tool is activated in an unloaded condition during the unloaded operational time.
4. The auxiliary wireless device of claim 3, wherein: the controller is further configured to: determine a non-operating movement time of the power tool over the time period, including: compare the PAA for each axis to a third acceleration threshold that is less than the second acceleration threshold, and set a movement time of the power tool to the time period when the PAA for at least one axis is less than the second acceleration threshold and greater than the third acceleration threshold, determine a cumulative non-operating movement time of the power tool based on non-operating movement times within the cumulative time period, and send the cumulative non-operating movement time to the WCU for transmission to the remote device; and the power tool is not activated or activated in the unloaded condition during the non- operating movement times.
5. The auxiliary wireless device of claim 4, wherein: the controller is further configured to:

determine a rest time of the power tool over the time period, including: set a rest time of the power tool to the time period when the PAA for each axis are less than the third acceleration threshold, determine a cumulative rest time of the power tool based on rest times within the cumulative time period, and send the cumulative rest time to the WCU for transmission to the remote device; and the power tool is not activated during the rest times.

6. The auxiliary wireless device of claim 1, wherein: determine the loaded operational time of the power tool includes: determine, based on 3-axis angular rate data, a peak absolute angular rate (PAAR) for each axis over the time period, compare the PAAR for each axis to an angular rate threshold, and set the loaded operational time of the power tool to the time period when the PAAR for at least one axis is greater than the angular rate threshold and the 3-axis angular rate data for at least one axis is sinusoidal with an angular rate frequency; and the angular rate frequency is related to user-induced movement of the power tool.

7. The auxiliary wireless device of claim 6, wherein: the controller is further configured to: determine an unloaded operational time of the power tool over the time period, including: set an unloaded operational time of the power tool to the time period when the PAAR for at least one axis is greater than the angular rate threshold and the 3-axis angular rate data for at least one axis is sinusoidal with a second angular rate frequency, determine a cumulative unloaded operational time of the power tool based on unloaded operational times within the cumulative time period; send the cumulative unloaded operational time to the WCU for transmission to the remote device; and the power tool is activated in an unloaded condition during the unloaded operational time, and the second angular rate frequency is related to a speed of the power tool.

8. The auxiliary wireless device of claim 1, wherein the controller is further configured to: store, in a memory, the IMU sensor data as timestamped IMU sensor data; and send the timestamped IMU sensor data to the WCU for communication over a wireless communication link.

9. The auxiliary wireless device of claim 8, wherein the controller is further configured to: determine, based on the timestamped IMU sensor data, at least one timestamped tool operational event including at least one of a total operational time, a high loaded operational time, a low loaded operational time, a trigger press time, a trigger release time, and an idle time; and send the timestamped tool operational events to the WCU for transmission to the remote device.

10. The auxiliary wireless device of claim 1, wherein the power tool is a drill, a driver, an impact driver, an impact wrench, a grinder, a miter saw, or a rotary hammer.

11. An auxiliary wireless device, comprising: a body removably attachable to a housing of a power tool; a wireless communication unit (WCU), supported by the body, the WCU including a wireless transceiver; an inertial measurement unit (IMU), supported by the body, the IMU configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data; and a controller, in communication with the WCU and the IMU, the controller configured to: execute a machine learning (ML) model to determine a loaded operational time of the power tool over a time period based on the IMU sensor data, determine a cumulative loaded operational time of the power tool based on loaded operational times within a cumulative time period, and send the cumulative loaded operational time to the WCU for transmission to a remote device, wherein the power tool is activated in a loaded condition during the loaded operational time.

12. The auxiliary wireless device of claim 11, wherein the ML model is trained to determine the loaded operational time of the power tool based on historical IMU sensor data that include one or more power tools operating in the loaded condition.

13. The auxiliary wireless device of claim 12, wherein: the ML model is trained to determine an unloaded operational time of the power tool based on historical IMU sensor data that include one or more power tools operating in an unloaded condition; and the controller is further configured to: execute the ML model to determine an unloaded operational time of the power tool over the time period based on the IMU sensor data, determine a cumulative unloaded operational time of the power tool based on unloaded operational times within the cumulative time period, and send the cumulative unloaded operational time to the WCU for transmission to the remote device, wherein the power tool is activated in the unloaded condition during the unloaded operational time.

14. The auxiliary wireless device of claim 13, wherein: the ML model is trained to determine a movement time of the power tool based on historical IMU sensor data that include one or more power tools that are not activated or activated in the unloaded condition; and the controller is further configured to: execute the ML model to determine a non-operating movement time of the power tool over the time period based on the IMU sensor data, determine a cumulative non-operating movement time of the power tool based on non-operating movement times within the cumulative time period, and send the cumulative non-operating movement time to the WCU for transmission to the remote device, wherein the power tool is not activated or activated in the unloaded condition during the non-operating movement time.

15. The auxiliary wireless device of claim 14, wherein: the ML model is trained to determine a rest time of the power tool based on the historical IMU sensor data that include one or more power tools that are not activated; and the controller is further configured to: execute the ML model to determine a rest time of the power tool over the time period based on the IMU sensor data, determine a cumulative rest time of the power tool based on rest times within the cumulative time period, and send the cumulative rest time to the WCU for transmission to the remote device, wherein the power tool is not activated during the rest time.

16. An auxiliary wireless device, comprising: a body removably attachable to a housing of a power tool; a wireless communication unit (WCU), supported by the body, the WCU including a wireless transceiver; an inertial measurement unit (IMU), supported by the body, the IMU configured to output IMU sensor data including at least one of 3-axis acceleration data and 3-axis angular rate data; and a controller, in communication with the WCU and the IMU, the controller configured to: determine, based on the IMU sensor data over a time period, an operation parameter of the power tool, the operation parameter including at least one of a type of power tool, a type of operation being performed by the power tool, and a type of output accessory mounted to the power tool; and send the operation parameter to the WCU for transmission to a remote device.

17. The auxiliary wireless device of claim 16, wherein the IMU sensor data includes at least one of: 3-axis acceleration data when the power tool is activated in a loaded condition; 3-axis angular rate data when the power tool is activated in the loaded condition; 3-axis acceleration data when the power tool is activated in an unloaded condition; and 3-axis angular rate data when the power tool is activated in the unloaded condition.

18. The auxiliary wireless device of claim 17, wherein the type of power tool includes at least one of a drill, a driver, an impact driver, an impact wrench, a grinder, a miter saw, and a rotary hammer.

19. The auxiliary wireless device of claim 17, wherein the type of operation includes at least one of drilling, driving, impact driving, heavy grinding, light grinding, polishing, removing material, and cutting.

20. The auxiliary wireless device of claim 17, wherein the type of output accessory includes at least one of a drill bit, a driver bit, a socket, a grinding wheel, a cutting wheel, and a circular saw blade.

21. The auxiliary wireless device of claim 17, wherein the controller is configured to determine the type of power tool by: determining a peak absolute value for each axis of the 3-axis acceleration data; comparing the peak absolute value for each axis of the 3-axis acceleration data to an acceleration threshold; processing the 3-axis angular rate data to determine a frequency of at least one sinusoidal waveform; comparing the frequency to an unloaded output shaft speed; and determining the type of power tool based on the comparison of the peak absolute values to the acceleration threshold and the comparison of the frequency to the unloaded output shaft speed.

22. The auxiliary wireless device of claim 21, wherein: the acceleration threshold is between 2 g and 8 g; the unloaded output shaft speed is between 1,800 revolutions per minute (rpm) and **3,000** rpm; and the controller is configured to determine the type of power tool to be an impact wrench when the peak absolute value of at least two axes of the 3-axis acceleration data is greater than the

acceleration threshold, and the frequency is between 30 Hz and 50 Hz.
23. The auxiliary wireless device of claim 21, wherein: the acceleration threshold is between 2 g and 6 g; the unloaded output shaft speed is between 7,200 rpm and 8,400 rpm; and the controller is configured to determine the type of power tool to be a grinder when the peak absolute value of at least two axes of the 3-axis acceleration data is greater than the acceleration threshold, and the frequency of a first sinusoidal waveform is between 120 Hz and 140 Hz.
24. The auxiliary wireless device of claim 23, wherein the controller is further configured to determine the type of power tool to be a grinder when the frequency of a second sinusoidal waveform is between 1 Hz and 5 Hz.
25. The auxiliary wireless device of claim 21, wherein: the acceleration threshold is between 2 g and 6 g; the unloaded output shaft speed is between 21,000 rpm and 23,400 rpm; and the controller is configured to determine the type of power tool to be a miter saw when the peak absolute value of at least two axes of the 3-axis acceleration data is greater than the acceleration threshold, and the frequency is between 350 Hz and 390 Hz.
26. The auxiliary wireless device of claim 25, wherein the controller is further configured to determine the type of power tool to be a miter saw when one axis of the 3-axis angular rate data includes a waveform pattern that includes a positive spike and a negative spike over about a 1 second time period.