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(54) **SYSTEMS AND METHODS FOR IDENTIFYING WEAR ON GRADING MACHINE**

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E02F 9/28 (2006.01)

(52) **U.S. Cl.**
CPC ***E02F 3/845*** (2013.01); ***E02F 9/265*** (2013.01); ***E02F 9/2883*** (2013.01)

(58) **Field of Classification Search**
CPC E02F 3/845; E02F 9/265; E02F 9/2883; E02F 9/264; E02F 9/267; E02F 9/2816; E02F 9/24; E02F 9/2833
See application file for complete search history.

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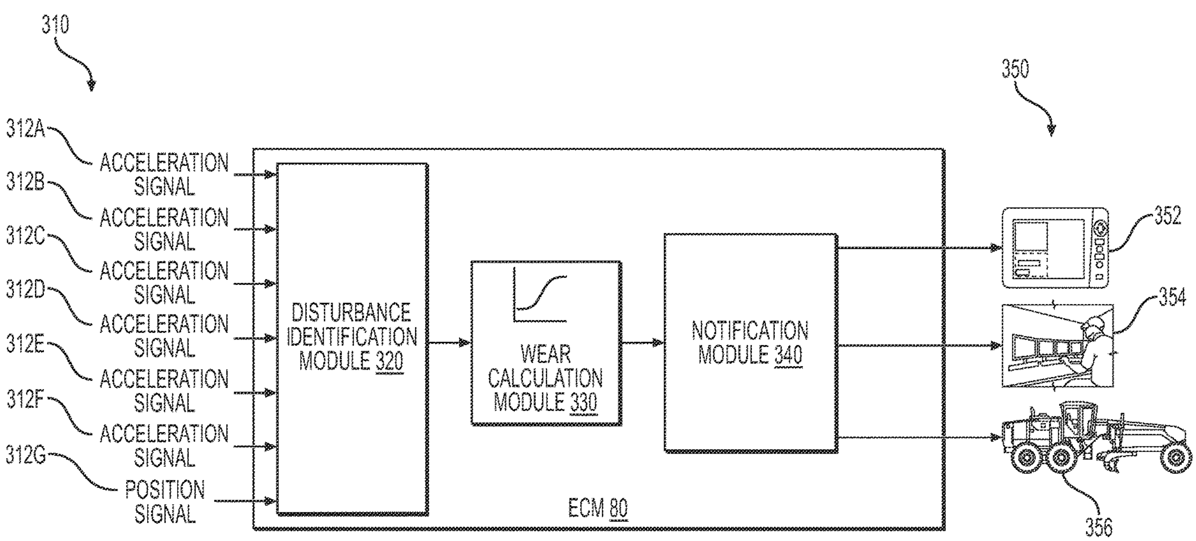
(57) **ABSTRACT**

A method for detecting wear in an implement system of a grading machine includes receiving acceleration information from a sensor connected to the implement system while the grading machine performs a task and estimating an incremental amount of wear in the implement system of the grading machine based on the acceleration information. The method also includes determining a cumulative amount of wear in the implement system of the grading machine and outputting a notification based on the cumulative amount of wear.

20 Claims, 4 Drawing Sheets



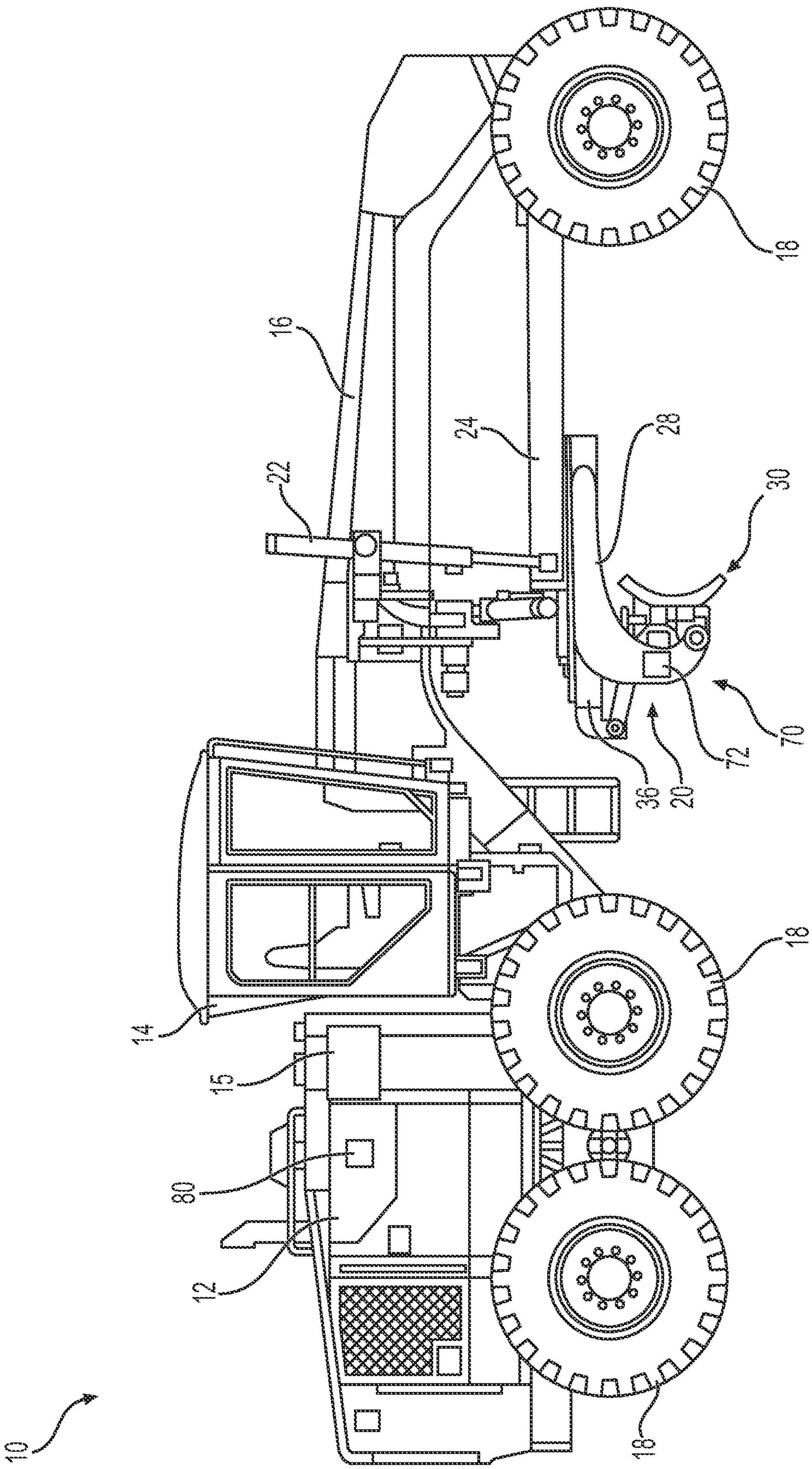


FIG. 1

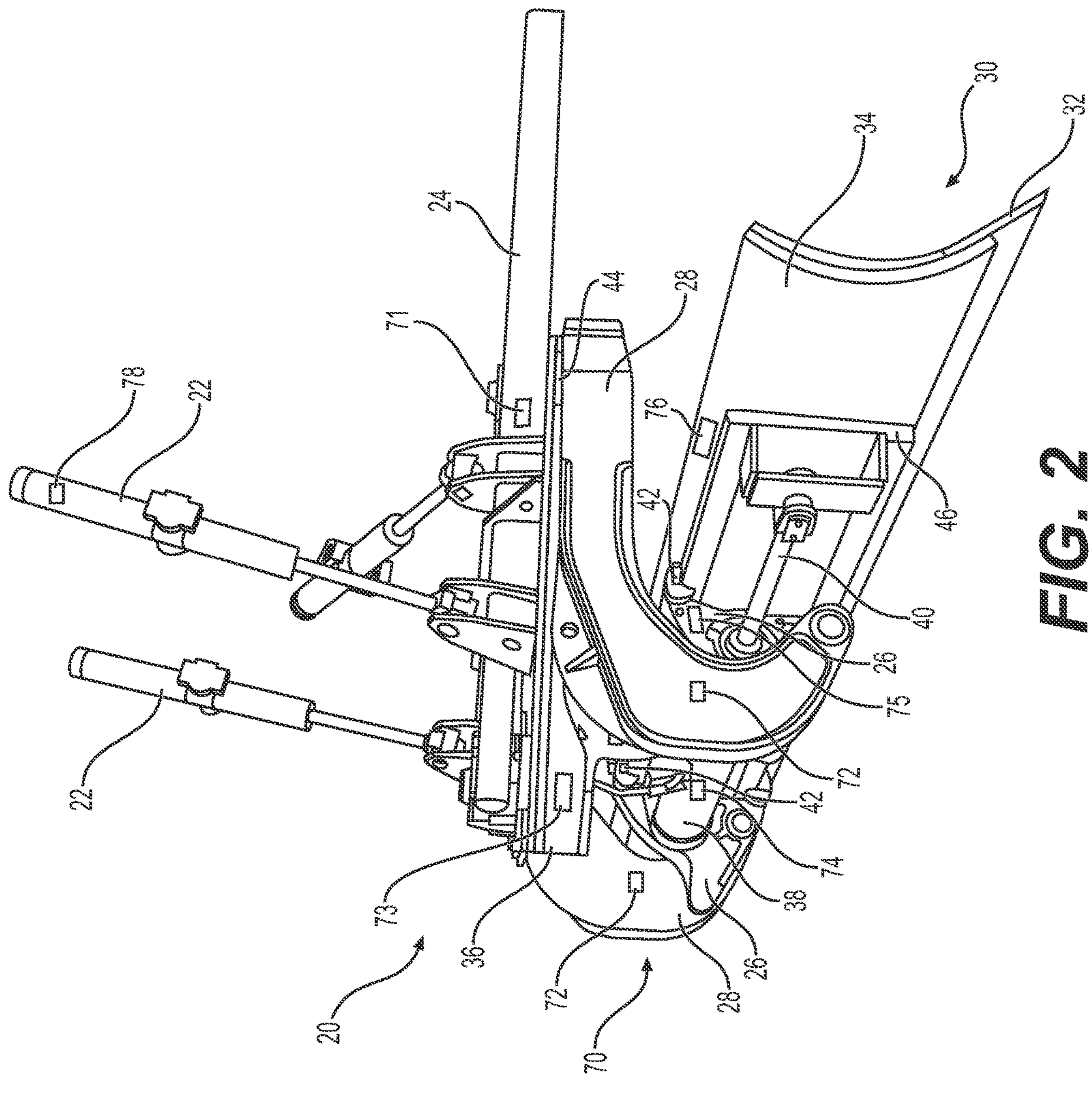


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FIG. 2

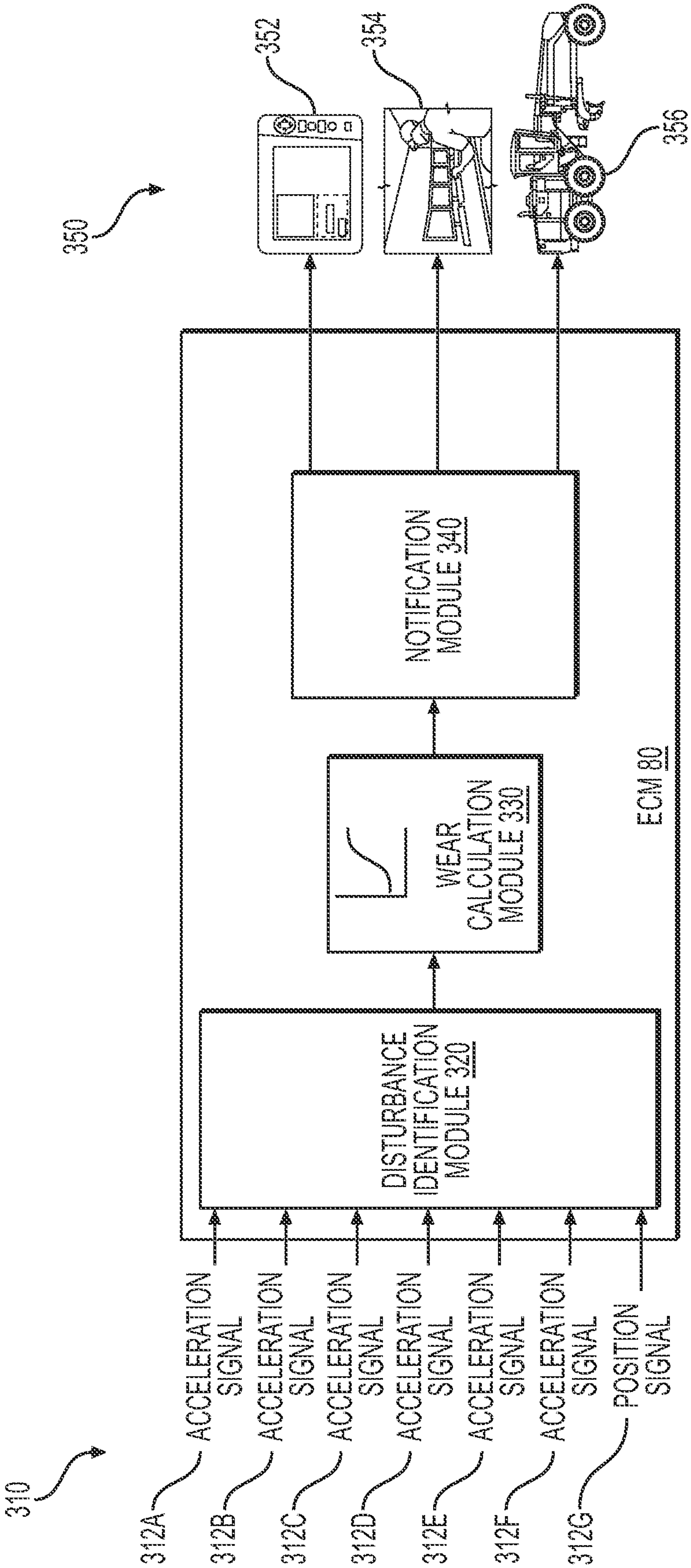
310
312A ACCELERATION SIGNAL
312B ACCELERATION SIGNAL
312C ACCELERATION SIGNAL
312D ACCELERATION SIGNAL
312E ACCELERATION SIGNAL
312F ACCELERATION SIGNAL
312G POSITION SIGNAL
DISTURBANCE IDENTIFICATION MODULE 320
WEAR CALCULATION MODULE 330
NOTIFICATION MODULE 340
ECM 80
350
352
354
356

FIG. 3

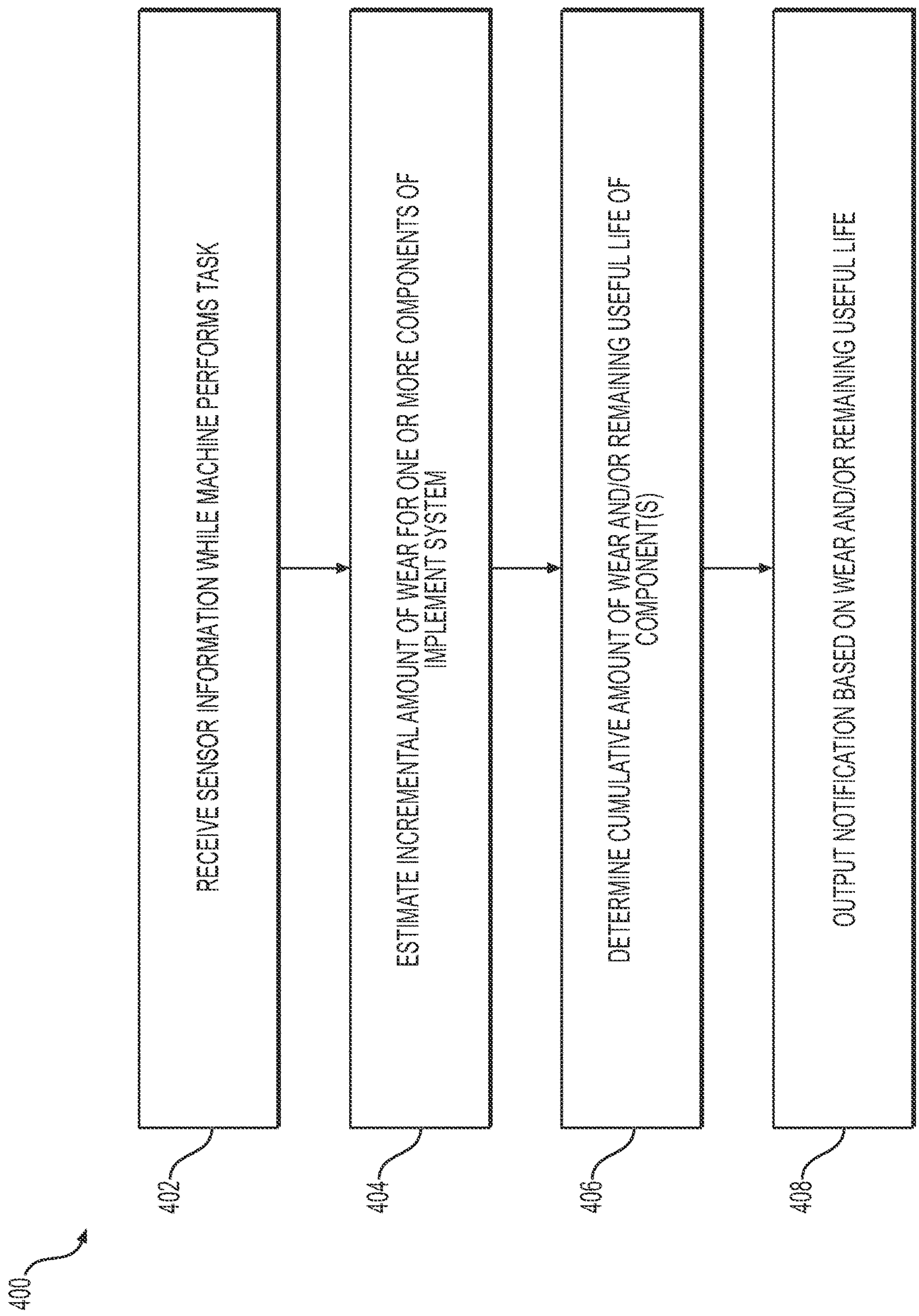
400
402
RECEIVE SENSOR INFORMATION WHILE MACHINE PERFORMS TASK
404
ESTIMATE INCREMENTAL AMOUNT OF WEAR FOR ONE OR MORE COMPONENTS OF IMPLEMENT SYSTEM
406
DETERMINE CUMULATIVE AMOUNT OF WEAR AND/OR REMAINING USEFUL LIFE OF COMPONENT(S)
408
OUTPUT NOTIFICATION BASED ON WEAR AND/OR REMAINING USEFUL LIFE

FIG. 4

SYSTEMS AND METHODS FOR IDENTIFYING WEAR ON GRADING MACHINE

TECHNICAL FIELD

The present disclosure relates generally to a grading machine, more particularly, to systems and methods for identifying a worn or loose blade of a grading machine.

BACKGROUND

Grading machines, including motor graders and tractors, include a cutting implement, such as a blade, that manipulates material on a worksite. The blade facilitates the placement of soil or other materials, in part due to the ability of the operator to position the blade as desired. The blade, connected to a frame of the machine, moves and levels material to provide a surface having a particular height and inclination. By necessity, the blade operates in a harsh environment and is subject to strong, sudden forces. Due to this, blades and other ground-engaging implements wear at a relatively fast rate, the rate of wear being affected by factors such as the type of material encountered by the blade, the position of the blade and associated components, and the speed at which the machine travels, among others. While the cutting edge of the blade itself wears over time, other components of the implement system for the blade also wear, and require periodic maintenance. Regular inspection, maintenance (e.g., adjustment), and replacement of the blade and implement system is necessary to support optimal performance of the grading machine. However, even with regular maintenance, it is possible that wear or damage to the implement system will be overlooked, especially when the implement wears or loosens more quickly than expected, or is improperly installed.

A system for measuring wear in a blade for a motor grader is described in U.S. Patent Application Publication No. 2020/0362542 ("the '542 publication") to Veasy et al. The system in the '542 publication evaluates wear by setting the blade on the ground. While the blade is on the ground, the system can evaluate wear on a cutting edge of a blade due to the position of the blade, in comparison to a previous measurement, also taken while the blade was placed on the ground. While the system of the '542 publication may be useful for measuring wear of a blade, the system relies on detection of the position of a blade itself to make this measurement. The system described in the '542 publication is therefore unable to evaluate wear on components of the implement system other than the blade, or to identify wear as it occurs (e.g., in real-time or near real-time manner).

The systems and methods of the present disclosure may solve one or more of the problems set forth above and/or other problems in the art. The scope of the current disclosure, however, is defined by the attached claims, and not by the ability to solve any specific problem.

SUMMARY

In one aspect, a method for detecting wear in an implement system of a grading machine may include receiving acceleration information from a sensor connected to the implement system while the grading machine performs a task and estimating an incremental amount of wear in the implement system of the grading machine based on the acceleration information. The method may also include determining a cumulative amount of wear in the implement system of the grading machine and outputting a notification based on the cumulative amount of wear.

In another aspect, a method for detecting wear in an implement system of a grading machine may include receiving a signal from a sensor connected to the implement system of the grading machine, the signal from the sensor being a function of movement of the implement system and estimating an amount of wear in the implement system of the grading machine based on the signal from the sensor, the amount of wear causing one or more components of the implement system to loosen over time. The method may also include outputting a notification based on the estimated amount of wear.

In yet another aspect, a system for detecting wear in a moldboard assembly of a grading machine may include a blade of the moldboard assembly, a drawbar connected to the moldboard assembly, a wear strip connected to the moldboard assembly, and an acceleration sensor connected to the moldboard assembly. The system may also include an electronic control unit configured to receive acceleration information generated with the acceleration sensor and calculate an amount of wear based on the acceleration information. The electronic control unit may also be configured to estimate a timing at which the amount of wear indicates that the wear strip requires replacement or adjustment and generate a notification in response to the estimated timing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side view of an exemplary grading machine, according to aspects of this disclosure.

FIG. **2** is a perspective view of a moldboard assembly and monitoring system of the grading machine shown in FIG. **1**.

FIG. **3** is a block diagram of an electronic control module, according to aspects of this disclosure.

FIG. **4** is a flowchart depicting an exemplary method for detecting wear in an implement system, according to aspects of the disclosure.

DETAILED DESCRIPTION

Both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the features, as claimed. As used herein, the terms "comprises," "comprising," "having," including," or other variations thereof, are intended to cover a non-exclusive inclusion such that a method or apparatus that comprises a list of elements does not include only those elements, but may include other elements not expressly listed or inherent to such a method or apparatus. In this disclosure, relative terms, such as, for example, "about," "substantially," "generally," and "approximately" are used to indicate a possible variation of ±10% in the stated value or characteristic. In this disclosure, the term "acceleration" is to be broadly interpreted as including both increases in speed and decreases in speed.

FIG. **1** illustrates an exemplary wear detecting system **10** for performing a grading operation. Wear detecting system **10** may include a machine **12**, a sensor system **70**, and a controller or electronic control unit or electronic control module (ECM) **80**. Machine **12** may be an earthmoving machine, such as a motor grader, or another type of machine that engages material with an implement and experiences wear, such as a track-type or wheeled tractor. Machine **12** may include a cabin **14**, a frame **16** supported on a machine chassis with cabin **14**, ground-engaging devices **18**, and an implement system **20**. Machine **12** may also include an internal combustion engine **15** or other power-generating device, a hydraulic system for actuating implement system **20**, and/or other components that facilitate the operation of system **10**.

Cabin **14** of machine **12** may include an operator station that includes controls for operating machine **12**. For example, cabin **14** may include input devices that allow an operator to propel machine **12** with ground-engaging devices **18**, which may include wheels, as shown in FIG. **1**, tracks, or other ground-engaging components. Engine **15** may be configured to combust fuel or otherwise generate power in response to an operator's interaction with these input devices, in order to propel machine **12** and operate implement system **20**.

Implement system **20** may include a moldboard assembly **30** and components for supporting moldboard assembly **30** from frame **16**, as well as components for positioning moldboard assembly **30**. Implement system **20** may include, in addition to moldboard assembly **30**, lift cylinders **22**, a drawbar **24** connected to lift cylinders **22**, one or more support linkages **28** connecting moldboard assembly **30** to drawbar **24**, and a circle **36** that enables rotational positioning of moldboard assembly **30**. Implement system **20** may also include components for moving moldboard assembly **30** laterally as compared to one or more support linkages **28**, such as a sideshift cylinder **38** and associated sideshift rod **40** (shown in FIG. **2**).

A sensor system **70** may include one or more sensors for detecting accelerations or other forces, hydraulic fluid pressures, component positions, and/or other types of information relating to machine **12** useful for identifying the occurrence of wear in one or more components of moldboard assembly **30**. In some aspects, sensor system **70** may include a sensor that detects information relating to one or more components of moldboard assembly **30** other than blade **32** (e.g., with sensors **71**, **72**, **73**, **74**, **75**, and/or **78**). While FIG. **1** shows a linkage sensor **72** connected to support linkage **28**, sensor system **70** may include one or more sensors at other locations (e.g., one or more of the locations illustrated in FIG. **2** and described below), instead of, or in addition to linkage sensor **72**. The sensors of sensor system **70** may be in communication with ECM **80** to enable ECM **80** to detect, quantify, and monitor wear. As one example, sensor system **70** may include sensors that facilitate the identification of wear that is associated with looseness of moldboard assembly **30**.

ECM **80** may be enabled, via programming, to generate outputs (e.g., outputs **350** shown in FIG. **3**) for identifying events associated with wear of implement system **20**, including moldboard assembly **30**. In particular, ECM **80** may be configured to detect events that contribute to wear of implement system **20** and/or to looseness of one or more components of implement system **20**, including moldboard assembly **30**. In particular, ECM **80** may be configured to identify events that cause incremental amounts of wear (e.g., wear to moldboard wear strips **42**, wear to circle wear strips **44**, or to both). ECM **80** may monitor incremental amounts of wear over a period of time, and determine (e.g., calculate) a cumulative amount of wear based on the incremental amounts of wear, each incremental amount of wear estimated with signals from one or more of the sensors of sensor system **70** during the operation of machine **12**.

ECM **80** may also be configured, via programming, to identify a remaining useful life of one or more components of implement system **20** based on signals from one or more of the sensors of sensor system **70**. While ECM **80** may monitor cumulative wear and identify looseness based on the cumulative wear, ECM **80** may also be configured to immediately identify severe wear or looseness conditions without the need to determine cumulative wear based on a series of estimated incremental amounts of wear. This may be performed, for example, by detecting relatively large forces with sensor system **70**. ECM **80** may be further configured to generate one or more outputs, described below, including a notification for display on a device associated with an operator of machine **12**, a notification for display at a fleet monitoring system or service center, and/or a notification presented by machine **12** (e.g., via a display present within cabin **14**). These notifications may be indicative of a cumulative amount of wear, a remaining useful life of a component of implement system **20**, and/or a current looseness condition of moldboard assembly **30**.

ECM **80** may embody a single microprocessor or multiple microprocessors that receive inputs **110** (FIG. **3**) and generate outputs **130** (FIG. **3**). ECM **80** may include a memory, a secondary storage device, a processor such as a central processing unit, or any other means for accomplishing a task consistent with the present disclosure. The memory or secondary storage device associated with ECM **80** may store data and software to allow ECM **80** to perform its functions, including the functions described with respect to FIG. **3** and one or more steps of method **400**, described below. Numerous commercially available microprocessors can be configured to perform the functions of ECM **80**. Various other known circuits may be associated with ECM **80**, including signal-conditioning circuitry, communication circuitry, and other appropriate circuitry.

Referring to FIG. **2**, moldboard assembly **30** may include a cutting blade **32** having a lower cutting edge, and a backplate **34** which may be a rear surface of blade **32** or a support member on which blade **32** is removably secured. Backplate **34** may include, or may be fastened to, a rear protrusion **46** or one or more rails. Protrusion **46** may connect moldboard assembly **30** to a circle **36** via support linkages **28**. Circle **36** may include a large gear configured to rotate with respect to drawbar **24** to enable positioning of moldboard assembly **30** about a vertical axis. A carrier **26** may connect backplate **34** and blade **32** to a horizontally-extending sideshift mechanism, such as a sideshift cylinder **38** that includes a sideshift rod **40**.

Implement system **20** may include one or more wear features that are designed as replaceable (e.g., sacrificial) and/or adjustable components, reducing the wear of other components that are larger, more difficult, and more costly to replace or adjust, such as carrier **26**, circle **36**, etc. For example, one or more moldboard wear strips **42** may be positioned between backplate **34** and support linkages **28**. In the example illustrated in FIG. **2**, moldboard wear strips **42** may be connected (e.g., removably fixed) to a respective carrier **26**. However, in other configurations, one or more moldboard wear strips **42** may be fixed to rear protrusion **46** of backplate **34**.

One or more circle wear strips **44** may be connected between circle **36** and drawbar **24**, or at other portions of implement system **20** that experience movement, wear strips **44** being secured in a manner that enables periodic replacement or adjustment. Thus, wear strips **44** may reduce the amount of wear experienced by circle **36** and other components of machine **12**, such as a yoke plate between circle **36** and drawbar **24**. Moldboard wear strips **42** and circle wear strips **44** may include metallic wear strips or shims, composite strips or shims, a stack of metallic and/or composite strips or shims, or other appropriate forms that wear at a faster rate as compared to other components of moldboard assembly **30** such as drawbar **24**, circle **36**, one or more support linkages **28**, etc. While moldboard wear strips **42** and strips **44** are referred to herein as "strips", the term "strips" is not restrictive to a particular shape or thickness. Moldboard wear strips **42**, strips **44**, or both, may be provided in any suitable shape, such as bars, plates, brackets, arcs, etc., and may be provided as a single member, or as a stack.

Sensor system **70** may include one or more of a drawbar sensor **71**, linkage sensor **72**, circle sensor **73**, sideshift sensor **74** (a sensor connected to sideshift cylinder **38** or adjacent to sideshift cylinder **38**), carrier sensor **75**, moldboard sensor **76**, and a cylinder sensor **78**. Sensors **71**, **72**, **73**, **74**, **75**, **76** and/or **78** may be one or more accelerometers or other device configured to detect disturbances, such as sudden accelerations or decelerations. Sensors **71-76** and **78** may include one or more inertial measurement units (IMUs) that include accelerometers that measure forces in three axes, including a first horizontal axis (x-axis), a second horizontal axis (y-axis), and a vertical direction (z-axis). If desired, sensors **71-76** and **78** may also be configured to detect rotation about the x-, y-, and z-axes. Sensors associated with hydraulic components, such as sensors **74** and **78**, may be position sensors or pressure sensors configured to detect a pressure of hydraulic fluid supplied to a hydraulic cylinder such that sensors **74** and **78** can detect unexpected movements or force placed on lift cylinders **22** or sideshift cylinder **38**.

Drawbar sensor **71** may be fixed to drawbar **24** to measure disturbances that are transferred from moldboard assembly **30** to drawbar **24**, or other disturbances experienced by machine **12**. Similarly, linkage sensors **72** may be fixed to a respective support linkage **28**, circle sensor **73** may be fixed to circle **36**, carrier sensor **75** may be fixed to a carrier **26**, and moldboard sensor **76** may be fixed to a component of moldboard **30**, such as a backplate **34**. Sensors **74** and **78** may be connected directly to a hydraulic cylinder to measure changes in a position of the cylinder, or may be connected to supply of hydraulic fluid (not shown) to measure pressure spikes in the hydraulic fluid.

FIG. **3** is a block diagram illustrating an exemplary configuration of ECM **80**. As shown in FIG. **3**, ECM **80** may be programmed or otherwise configured with a disturbance identification module **320**, a wear calculation module **330**, and a notification module **340**. ECM **80** may receive a plurality of inputs **310**, including inputs from the one or more sensors of sensor system **70**. ECM **80** may be configured to generate one or more outputs **350** which enable ECM **80**, via notification module **340**, to communicate a wear condition of implement system **20**, communicate a loose condition of implement system **20**, and/or communicate a remaining useful life of implement system **20**. ECM **80** may be a standalone controller dedicated to monitoring wear, or may generate outputs for controlling one or more other systems of machine **12**, such as an internal combustion engine, hydraulic system, etc.

Inputs **310**, including signals **312**A-**312**G, may be received and processed with disturbance identification module **320** of ECM **80**. Signals **312**A-**312**F may be acceleration signals generated by sensors **71**, **72**, **73**, **74**, **75**, and **76**, respectively. Signals **312**A-**312**F may include acceleration information for a plurality of different axes, such as the above-described x-, y-, and z-axes. If desired, signals **312**A-**312**F may include acceleration information for rotation about one or more of these axes. Position signal **312**G may be an absolute position signal, that represents a position of a hydraulic component of implement system **20**. In particular, position signal **312**G may indicate a position of a movable component (e.g., a rod) of one or more lift cylinders **22**, sideshift cylinder **38**, or another hydraulic component of implement system **20**. If desired, one or more of signals **312**A-**312**F may be a position signal, instead of or in addition to an acceleration signal. For example, signal **312**A may include a position signal indicative of a position of drawbar **24**. One or more of signals **312**A-**312**G may be a pressure signal indicative of a pressure of hydraulic fluid. Thus, signals **312**A-**312**G may be configured to indicate wear that occurs when hydraulic fluid increases unexpectedly.

Disturbance identification module **320** may be configured to identify wear events, or disturbances, indicated by one or more of signals **312**A-**312**G. In one aspect, disturbance identification module **320** may receive one or more of signals **312**A-**312**G to identify a wear event according to the magnitude and/or direction indicated by these signals. For example, disturbance identification module **320** may determine that a wear event has occurred when an acceleration in any one or more axes (e.g., the above-described x-, y-, and/or z-axes) exceeds a predetermined threshold value. Additionally or alternatively, disturbance identification module **320** may be configured to determine that a disturbance, also referred to herein as a wear event, has occurred when acceleration is detected in a particular axis, such as a vertical or z-axis, while ignoring other axes (e.g., a horizontal axis in which acceleration tends to occur when moving material at a steady rate). In other configurations, disturbance identification module **320** may determine that wear has occurred based on accelerations in multiple axes. For example, disturbance identification module **320** may identify the occurrence of wear when a sensed vertical acceleration exceeds a vertical threshold value, when a sensed horizontal acceleration exceeds a horizontal threshold value, or when both accelerations exceed their respective threshold values. In some configurations, vertical and horizontal thresholds may be different from each other. For example, the vertical threshold value may be lower (e.g., a requiring a smaller amount of acceleration to trigger identification of a disturbance) in comparison to a horizontal threshold.

In configurations where disturbance identification module **320** is configured to determine the occurrence of a disturbance, or wear event, based on position signal **312**G, module **320** may estimate wear based on the position of hydraulic cylinder (e.g., by calculating the rate at which this position changes). In these or other configurations, disturbance identification module **320** may be configured to identify, based on position signal **312**G, when a position of a hydraulic cylinder changes in the absence of the issuance of a command to cause this change of position. In configurations where signal **312**G is provided as a pressure signal that indicates a pressure of hydraulic fluid, disturbance identification module **320** may monitor this signal for a pressure spike in the hydraulic fluid (e.g., a pressure value that exceeds a predetermined threshold).

Wear calculation module **330** may be configured to estimate a severity of wear events that are identified by disturbance identification module **320**. For example, wear calculation module **330** may be configured to receive a magnitude and/or direction of acceleration from disturbance identification module **320**, when module **320** identifies the occurrence of a wear event. Wear calculation module **330** may include one or more maps, look-up tables, or other data-storing structures, that enable the estimation of an incremental amount of wear. For example, wear calculation module **330** may be configured to determine a severity or magnitude of an incremental amount of wear based on the magnitude and direction of an impact represented by one or more of signals **312**A-**312**G.

Wear calculation module **330** may also be configured to monitor a cumulative amount of wear that represents the total amount of wear that has been experienced by one or more components of implement system **20**. For example, the cumulative amount of wear may represent the sum of the incremental amounts of wear. The cumulative amount of wear may represent a "replacement wear" that can be addressed by replacing one or more components associated with this wear. When replacement is performed, the cumulative amount of wear, in this example, replacement wear, may be reset (e.g., set to a value of zero) by performing a "replacement reset" operation each time a monitored component of implement system **20** is replaced. ECM **80** may be notified that a monitored component has been replaced by a user interaction with an input device of machine **12** or by interacting with any other device associated with machine **12**, including any of the devices that receive one or more of outputs **350**.

If desired, the cumulative amount of wear may represent an "adjustment wear" that can be addressed by performing an adjustment to one or more components of implement system **20**, without the need to replace the component. An adjustment may include tightening a loose component or changing a position of a component, for example. The cumulative amount of wear (adjustment wear) may be reset by performing an "adjustment reset" operation after the adjustment is performed. In some aspects, wear calculation module **330** may track replacement wear (for components that are replaced when wear reaches a particular amount) separately from adjustment wear (for components that are adjusted when wear reaches a particular amount). Replacement wear and adjustment wear may be monitored for different components such that replaceable components are associated with a replacement wear and adjustable components are associated with an adjustment wear. However, in at least some configurations, a single component or group of components, such as wear strips **42** and/or **44**, may be adjusted one or more times before being replaced and may be associated with both an adjustment wear that is reset using an adjustment reset operation, and a replacement wear that is reset with a replacement reset operation. The adjustment wear may therefore be independent of the replacement wear for the same component.

Notification module **340** may be configured to receive the incremental amount of wear from wear calculation module **330**. Based on this incremental amount of wear or based on a severity of a single wear event, notification module **340** may be configured to output a notification. This notification may be generated, from ECM **80**, to one or more of an operator display, service center, or machine **12** itself. In particular, notification module **340** may be configured to generate one or more notifications, as outputs **350**, the notifications including an operator display notification **352** (e.g., a notification displayed on a display within cabin **14** of machine **12**, a personal device associated with the operator such as a cellular phone or other handheld device, tablet, laptop, remote computing system, etc.), and/or a management notification **354** (e.g., a portable or stationary computing system monitored by an entity other than an operator located on-site with machine **12**, such as a fleet manager, supervisor, service center etc.). If desired, outputs **350** may include a machine command **356**, which may cause a particular action of machine **12** to prevent damage. As one example, machine command **356** may include raising moldboard assembly **30** with lift cylinders **22** to prevent cutting blade **32** from encountering material.

Notification module **340** may be configured to receive the cumulative amount of wear and compare the cumulative amount of wear to a threshold amount of wear. As described above, the cumulative amount of wear may represent a replacement wear and/or an adjustment wear. When monitoring replacement wear, the threshold amount of wear may represent an amount of wear at which it is desirable or required to replace moldboard wear strip **42** and/or circle wear strip **44**. When monitoring adjustment wear, the threshold amount of wear may represent an amount of wear at which one or more components should be adjusted. For each type of wear, the threshold amount of wear may be the maximum permitted amount of wear, or an amount of wear approaching the maximum permitted amount of wear. In the case of replacement wear, the threshold amount of wear may correspond to an amount of wear at which strip **42** and/or strip **44**, for example, have no remaining useful life or little remaining useful life. When a plurality of different components are monitored, such as moldboard wear strips **42** and strips **44**, each component may have a different cumulative amount of wear associated with it, such that these components are monitored independent of each other and such that replacement and independent wear are monitored separately for each component. In these configurations, notification module **340** may output a notification **352** and/or **354** based on the monitored component with the lower remaining useful life. Additionally, notification **352** and/or **354** may indicate the type of wear being monitored or the type of action (e.g., an adjustment or replacement) that should be performed.

When wear members, such as strips **42** and/or **44**, are worn (e.g., have experienced significant material loss) so as to have no or little remaining useful life, the cumulative wear and associated loss of material may tend to cause looseness in one or more components of moldboard assembly **30**. For example, wear in strips **42** and/or **44** may cause looseness of blade **32** or other parts of moldboard assembly **30**. Thus, notification module **340** may be configured to output a notification (e.g., operator display notification **352** and/or management notification **354**) that is based on the identification of looseness in moldboard assembly **30**, according to a wear threshold associated with the component of assembly **20** that wears at the fastest rate (e.g., strips **42** and/or **44**).

If desired, notification module **340** may also be configured to determine a remaining useful life of one or more components of assembly **20** (including determining the remaining useful life of assembly **20** as a whole) based on the difference between the cumulative amount of wear and the threshold amount of wear. The remaining useful life may be notified and displayed as a percentage (e.g., an amount of remaining life and/or an amount of useful life that has been consumed). Additionally or alternatively, the remaining useful life may be notified and displayed as an amount of operating time (e.g., an estimated remaining number of operating hours before the remaining useful life is exhausted and/or replacement or adjustment is recommended). Thus, the remaining useful life may be prognostic, indicating a remaining amount of operating time (e.g., 48 hours, 24 hours, 12 hours, 100%, 50%, 25%, etc.), or diagnostic when little or no remaining useful life is present (e.g., a notification indicating the presence of looseness). Each of these notifications, whether prognostic or diagnostic, may correspond to an estimation of timing at which an amount of wear corresponds to the need to replace or adjust one or more components of assembly **20**.

If desired, notification module **340** may be configured to generate one or more outputs **350** based on an instantaneous amount of wear calculated with wear module **330**. For example, disturbance identification module **320** may receive one or more signals **312**A-**312**G that, when evaluated by wear calculation module **330**, indicate a large amount of wear and/or looseness in moldboard assembly **30**. This may enable notification module **340** to generate one or more of outputs **350** when a single measurement, or a series of measurements taken over a relatively short period of time (e.g., measurements taken with sensor system **70** over a period of time that is less than 24 hours, less than 12 hours, or less than 1 hour), indicates the existence of a relatively large amount of wear and/or a loose moldboard assembly **30**. Thus, in some aspects, ECM **80** may be configured to identified a damaged and/or improperly installed moldboard assembly **30**, or identify a component with no remaining useful life, independent of a cumulative amount of wear.

INDUSTRIAL APPLICABILITY

Wear detecting system **10**, including sensor system **70** and ECM **80** may be useful in any machine that includes an implement that is subject to wear, such as a motor grader having a moldboard, as shown in FIG. **1**, dozers, or other earthmoving machines. System **10** may also be employed in other systems that experience regular wear, such as other types of machines or vehicles (e.g., hauling trucks, tractors, excavators, etc.). System **10** may monitor wear continuously or intermittently during the operation of machine **12**, and may store and retrieve wear conditions (e.g., a cumulative amount of wear), such that wear can be tracked in one or more components of machine **12** over a multiple operations, tasks, or jobs. Further, system **10** may be measure and identify wear in real-time or near-time.

FIG. **4** is a flowchart illustrating an exemplary method **400** for detecting wear in an implement system of a machine, such as grading machine **12**. Method **400** may be performed while machine **12** performs a grading operation. For example, ECM **80** may perform steps **402**, **404**, **406**, and **408** during an earthmoving job, such as grading, while the machine performs a task or travels. Alternatively, method **400** may be performed intermittently at regular irregular intervals. When method **400** is performed during grading, method **400** may enable real time or near-real time monitoring without the need to discontinue propulsion of machine **12** and without the need to place implement(s) of machine **12** in a specific position. Thus, method **400** may enable detection of wear events as they occur, facilitating the generation of outputs **350** in a timely manner. If desired, method **400** may be performed while commanding blade **32** of moldboard assembly **30** to remain in a constant position as compared to machine **12**.

A step **402** of method **400** may include receiving sensor information, with ECM **80**, from sensor system **70**. This sensor information may be received by ECM **80** during the operation of machine **12**, and in particular, during a grading operation during which machine **12** is propelled by an engine or other power source such that wheels, tracks, or other ground-engaging devices **18** allow machine **12** to traverse a worksite. Step **402** may include performing a task, such as earthmoving work, by operating implement system **20** to perform grading while machine **12** is propelled.

A step **404** may include estimating one or more incremental amounts of wear with ECM **80** based on signals received from sensor system **70**. An incremental amount of wear may be estimated each time one or more signals from sensor system **70**, such as signals **312**A-**312**G, include information indicative that a wear event has occurred. For example, wear calculation module **330** may determine that a wear event has occurred when an acceleration indicated by one or more of signals **312**A-**312**F is greater than a predetermined threshold and/or when position signal **312**G identifies the presence of an unexpected force applied to a hydraulic component, as described above. Step **404** may include estimating wear based on the direction in which the acceleration or force is measured. For example, step **404** may include determining, with disturbance identification module **320**, that wear has occurred based on the direction of the acceleration or movement. In one example, step **404** may include determining that wear has occurred when the force and/or movement identified with sensor system **70** is in a vertical direction (e.g., a z-axis, as described above). The severity of the wear and the corresponding magnitude of the incremental amount of wear may be estimated by retrieving one or more wear values from a look-up table, map, etc., based on the measured magnitude and/or direction of acceleration or movement detected with sensor system **70**.

A step **406** of method **400** may include determining a cumulative amount of wear, a remaining useful life, or both, of the component(s) monitored with ECM **80**. The cumulative amount of wear may be determined by periodically updating a running value, calculated with wear calculation module **330** of ECM **80**, that represents the amount of wear (e.g., replacement wear or adjustment wear) that has accrued in implement system **20**. This wear may be monitored over a plurality of different operations of wear detecting system **10**. Step **406** may include determining the remaining useful life of implement system **20**, and in particular, determining that remaining useful life has been exhausted, when the cumulative amount of wear exceeds this threshold. This determination may include identifying looseness in moldboard assembly **30** due to little or no remaining useful life of implement system **20**, and may indicate that a current time exceeds the estimated time at which a component of implement system **20** requires replacement or adjustment. Additionally or alternatively, step **406** may include identifying a lack of remaining useful life (e.g., looseness in moldboard assembly **30**) based on an instantaneous amount of wear measured with wear calculation module **330** in step **404**.

A step **408** may include outputting a notification based on the cumulative amount of wear and/or in response to determining that the remaining useful life of implement system **20** has been exhausted or has been depleted below a predetermined threshold. The notification may be generated as one or more of outputs **350**, and may be transmitted to an offsite monitoring system, e.g., as operator display notification **352** and/or management notification **354** sent to an offsite device. In methods where wear detecting system **10** monitors wear of multiple components, such as moldboard wear strips **42** and circle wear strips **44**, the notification may indicate which component is associated with the notification.

While steps **402**, **404**, **406**, and **408** have been described in an exemplary sequence, as understood, one or more of these steps may be performed simultaneously or performed and/or repeated in a different order. Moreover, any two or more of these steps may be performed simultaneously and/or at overlapping periods of time. As discussed above, each of these steps may be performed while machine **12** is in motion.

The system and method disclosed herein may facilitate accurate identification of wear conditions of wear materials in a machine, such as a motor grader. The prompt identification of wear material that has used a significant amount of life may enable timely maintenance, preventing rework and improving efficiency. Identification of implement system wear and/or blade looseness can ensure that the machine, such as motor grader, maintains tight grade tolerances. The system and method may facilitate real-time wear tracking, or immediate identification of looseness, enabling timely maintenance and reducing machine downtime.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed system and method without departing from the scope of the disclosure. Other embodiments of the system and method will be apparent to those skilled in the art from consideration of the specification and system and method disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims and their equivalents.

What is claimed is:

1. A method for detecting wear in an implement system of a grading machine, the method comprising:
- with at least one processor:
  - receiving acceleration information from a sensor connected to the implement system while the grading machine performs a task that causes an incremental amount of wear in the implement system;
  - estimating, based on the acceleration information, the incremental amount of wear in the implement system of the grading machine;
  - determining, based on the estimated incremental amount of wear, a cumulative amount of wear in the implement system of the grading machine; and
  - outputting a notification based on the cumulative amount of wear; and
- performing replacement or adjustment of the implement system based on the output notification.

2. The method of claim **1**, wherein the incremental amount of wear and the cumulative amount of wear are both associated with a component of the implement system connected to a cutting blade and to a drawbar.

3. The method of claim **2**, wherein the component of the implement system is a wear strip.

4. The method of claim **1**, wherein the sensor is connected to a drawbar, a circle, a support linkage, a sideshift mechanism, or a moldboard.

5. The method of claim **4**, wherein the sensor is an accelerometer configured to detect acceleration in at least a horizontal direction and a vertical direction.

6. The method of claim **5**, wherein the incremental amount of wear is estimated based on an acceleration in the vertical direction that is detected with the accelerometer.

7. The method of claim **1**, wherein the receiving comprises receiving the acceleration information from the sensor connected to the implement system while the grading machine performs the task of grading a worksite.

8. A method for detecting wear in an implement system of a grading machine, the method comprising:
- with at least one processor:
  - receiving a signal from a sensor connected to the implement system of the grading machine, the signal from the sensor being a function of movement of the implement system which causes wear to the implement system;
  - estimating an amount of wear in the implement system of the grading machine based on the signal from the sensor, the amount of wear causing one or more components of the implement system to loosen over time; and
  - outputting a notification based on the estimated amount of wear; and
- performing maintenance of the implement system based on the output notification.

9. The method of claim **8**, wherein the amount of wear is estimated based on a magnitude and direction indicated in the signal from the sensor.

10. The method of claim **8**, wherein the one or more components of the implement system includes a moldboard.

11. The method of claim **8**, wherein the sensor is connected to or connected adjacent to a sideshift cylinder of the grading machine.

12. A method for detecting wear in a moldboard assembly of a grading machine with a system comprising:
- a blade of the moldboard assembly,
- a drawbar connected to the moldboard assembly,
- a wear strip connected to the moldboard assembly,
- an acceleration sensor connected to the moldboard assembly, and
- an electronic control unit, the method comprising:
- with the electronic control unit:
  - receiving acceleration information generated with the acceleration sensor, the acceleration information indicating that an acceleration of the moldboard assembly exceeds a predetermined acceleration during a task that causes wear to the moldboard assembly,
  - calculating an amount of wear based on the acceleration information,
  - estimating a timing at which the amount of wear indicates that the wear strip requires replacement or adjustment based on the calculated amount of wear, and
  - generating a notification in response to the estimated timing; and
- replacing or adjusting the wear strip based on the generated notification.

13. The method of claim **12**, wherein the notification indicates a need to replace or adjust the wear strip, the wear strip being connected between the blade and a support linkage for supporting the blade.

14. The method of claim **12**, wherein the estimating comprises estimating the timing based on a direction of acceleration measured with the acceleration sensor.

15. The method of claim **12**, wherein the amount of wear is calculated based on the acceleration information including acceleration in a vertical direction which is detected with the acceleration sensor.

16. The method of claim **12**, wherein the calculating comprises calculating the amount of wear of the blade of the moldboard assembly while commanding the blade to remain in a constant position.

17. The method of claim **12**, wherein the notification indicates the estimated timing at which the wear strip will require replacement or adjustment.

18. The method of claim **12**, wherein the generating the notification comprises generating the notification and transmitting the notification to an operator device.

19. The method of claim **12**, wherein the generating the notification comprises generating the notification and transmitting the notification to an offsite monitoring system.

20. The method of claim **12**, wherein the electronic control unit is configured to generate a command to control a position of the moldboard assembly when a current timing exceeds the estimated timing.

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