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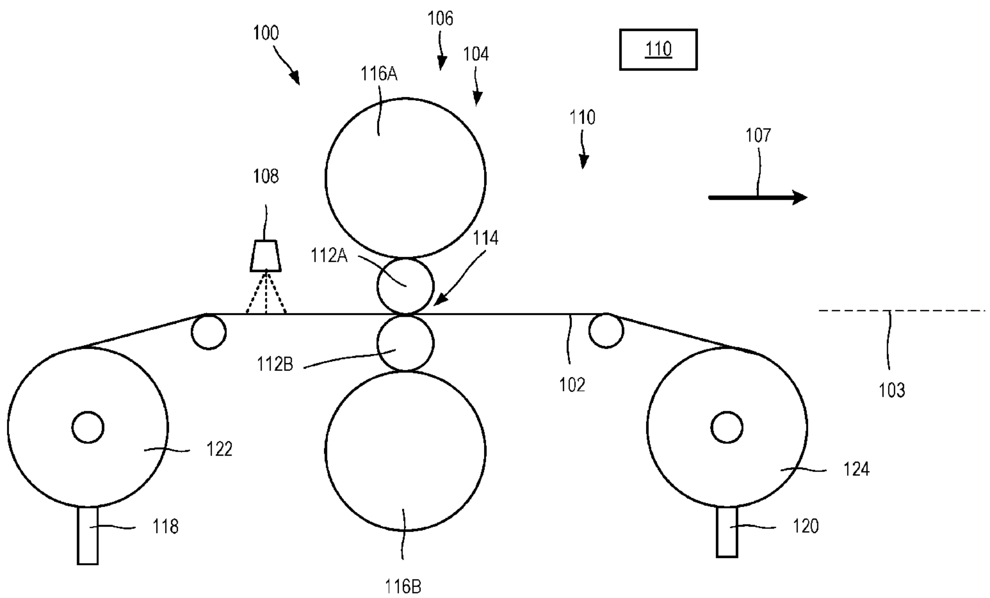


**FIG. 1**

(57) **Abstract:** A metal processing system (100) for a metal strip includes a camera (108) and a controller (110). The camera (108) is positioned to capture at least one image of a portion of the metal strip. The controller (110) is communicatively coupled to the camera (108) and may acquire the at least one image of the portion of the metal strip from the camera (108), determine an edge of the metal strip in the at least one image, determine a strip position of the metal strip based on the determined edge of the metal strip, and generate a control response for a rolling mill (106) based on the determined strip position. A method of processing a metal strip includes identifying an edge of the metal strip in visual data, determining a strip position based on the identification of the edge, and generating a control response based on the determined strip position.

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# IMPROVED ROLLING SYSTEMS AND METHODS USING OPTICAL-BASED STRIP CENTRALIZATION

## CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** This application claims the benefit of and priority to U.S. Provisional Patent Application No. 63/513,944, filed on July 17, 2023, the content of which is hereby incorporated by reference in its entirety.

## FIELD OF THE INVENTION

**[0002]** This application relates to the processing of metal substrates, such as but not limited to aluminum or aluminum alloy metal sheets, and more particularly to systems and methods for controlling flatness of a head or first lap of a metal substrate.

## BACKGROUND

**[0003]** Metal rolling can be used for forming metal strips (e.g., plates, sheets, foils, slabs, etc.) (hereinafter “metal substrates”) from stock such as ingots or thicker metal strips. Depending on the desired properties of the final metal product, the metal substrate may be hot rolled, cold rolled, and/or warm rolled. Hot rolling generally refers to a rolling process where the temperature of the metal is above the recrystallization temperature of the metal. Cold rolling generally refers to a rolling process where the temperature of the metal is below the recrystallization temperature of the metal. Warm rolling generally refers to a rolling process where the temperature of the metal is below the recrystallization temperature but above the temperature during cold rolling.

**[0004]** Strip centralization is important in a rolling mill, and without proper centralization, the metal strip may be at an incorrect and/or inconsistent position within the mill. Such incorrect positioning may lead to issues such as but not limited to flatness issues, asymmetric tension distribution in strip edges, high risk and rate of strip breakage (e.g., due to overstressed edges), etc. Traditional approaches for controlling strip centralization have been to manually center the metal strip before the start of rolling. However, such approaches may be susceptible to operator error, and centering of the metal strip after start-up and during rolling is not possible.

## SUMMARY

**[0005]** Embodiments covered by this patent are defined by the claims below, not this summary. This summary is a high-level overview of various embodiments and introduces some

of the concepts that are further described in the Detailed Description section below. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used in isolation to determine the scope of the claimed subject matter. The subject matter should be understood by reference to appropriate portions of the entire specification of this patent, any or all drawings, and each claim.

**[0006]** According to certain embodiments, a rolling system for a metal strip includes a rolling mill, an optical sensor, and a controller. The rolling mill includes at least one work stand for receiving the metal strip. The controller is operably connected to the optical sensor and the rolling mill and may determine a strip position of the metal strip relative to the at least one work stand based on visual data from the optical sensor and generate a control response for the rolling mill based on the determined strip position.

**[0007]** According to some embodiments, a metal processing system for a metal strip includes a camera positioned to capture at least one image of a portion of the metal strip and a controller communicatively coupled to the camera. The controller may acquire the at least one image of the portion of the metal strip from the camera, determine an edge of the metal strip in the at least one image, determine a strip position of the metal strip based on the determined edge of the metal strip, and generate a control response for a rolling mill based on the determined strip position.

**[0008]** According to certain embodiments, a method of processing a metal strip includes receiving visual data from at least one camera of a portion of the metal strip being processed by a rolling mill. The method includes identifying an edge of the metal strip in the visual data, determining a strip position in the rolling mill and/or the metal processing system based on the identification of the edge, and generating a control response for the rolling mill based on the determined strip position.

**[0009]** Various implementations described herein can include additional systems, methods, features, and advantages, which cannot necessarily be expressly disclosed herein but will be apparent to one of ordinary skill in the art upon examination of the following detailed description and accompanying drawings. It is intended that all such systems, methods, features, and advantages be included within the present disclosure and protected by the accompanying claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0010]** The specification makes reference to the following appended figures, in which use of like reference numerals in different figures is intended to illustrate like or analogous components.

**[0011]** FIG. 1 illustrates a metal processing system according to embodiments.

**[0012]** FIG. 2 is another view of a portion of the metal processing system of FIG. 1.

**[0013]** FIG. 3 illustrates a method for processing a metal strip with the metal processing system of FIG. 1 according to embodiments.

## DETAILED DESCRIPTION

**[0014]** Described herein are metal processing systems and methods with one or more optical sensors for improved determination of strip centralization and control based on the strip centralization. Metal processing systems may include, but are not limited to, hot rolling mills, cold rolling mills, and warm rolling mills. As such, while the following description refers to cold rolling mills, the embodiments described herein are not limited to such metal processing systems and may be utilized in various other types of metal processing systems as desired. The optical sensors may be various devices, cameras or other imaging devices configured to obtain one or more images of a portion of a metal strip. As non-limiting examples, the optical sensors may include optical or video cameras, single or multi-stereo cameras, laser-based cameras, thermal (e.g., infrared) cameras, visible light cameras, red-green-blue depth (RGB-D) cameras, combinations thereof, and/or other devices as desired. In certain embodiments, the systems and methods described herein may have easy installation, low cost, and provide accurate measurements. In various embodiments, the systems and methods described herein may be utilized in harsh environments found in a rolling mill such as an area with poor visibility due to fumes and/or an area with high temperatures. In certain embodiments, the systems and methods described herein may allow for determination of strip position in a vertical direction and/or a horizontal direction.

**[0015]** The systems and methods described herein may utilize the improved strip position detection to improve other rolling processes during various stages of rolling (e.g., start-up, steady state, etc.). As non-limiting examples, the systems and methods described herein may utilize the strip position measurements to control actuators for strip centralization, flatness control, steering, edge tension, etc. In other embodiments, the systems and methods described herein may utilize the strip position measurements as feedback control for other processes of the rolling mill as desired. The feedback control based on measured strip position in turn may provide improved flatness control, reduce bad starts and losses in productivity, and/or increase overall material recovery of the process. Various other benefits and advantages may be realized with the systems and methods described herein, and the aforementioned benefits and advantages should not be considered limiting.

**[0016]** FIGS. 1 and 2 illustrate an example of a metal processing system 100 for a metal strip 102 according to embodiments. In various embodiments, the metal strip 102 may be various metals as desired, including but not limited to aluminum, aluminum alloys, steel, or other metals as desired. In some examples, metal strip 102 may be aluminum or an aluminum alloy in the 1xxx series, 2xxx series, 3xxx series, 4xxx series, 5xxx series, 6xxx series, 7xxx series, 8xxx series and/or any other aluminum or aluminum alloy. The metal processing system 100 may include a rolling mill 104 with at least one work stand 106, one or more optical sensors 108, and optionally a controller 110 (processor and/or memory). As illustrated in FIG. 1, the rolling mill 104 may also include an unwind coiler 118 and/or a rewind coiler 120 for receiving and unwinding a coil 122 of the metal strip 102 and/or forming a coil 124 of the metal strip 102.

**[0017]** In FIGS. 1 and 2, the rolling mill 104 is a cold rolling mill, although in other embodiments the rolling mill 104 may be a hot rolling mill and/or a warm rolling mill. The rolling mill 104 illustrates a single work stand 106, however in other embodiments, the rolling mill 104 may include any number of work stands 106 as desired, such as two work stands 106, three works stands, 106, etc. Each work stand 106 of the rolling mill 104 includes a pair of vertically aligned work rolls 112A-B that define a roll gap 114 for receiving the metal strip 102 during rolling and along a passline 103. As illustrated in FIGS. 1 and 2, the work stand 106 may include one or more back up rolls 116A-B, and optionally the work stand 106 may include one or more intermediate rolls between the back up rolls 116A-B and the work rolls 112A-B. During a rolling process, the metal strip 102 may be moved in a processing direction 107 and may be unwound from the coil 122 on the unwind coiler 118, guided to the rolling mill 104 for rolling, guided to the rewind coiler 120, and rewound into the coil 124.

**[0018]** In various embodiments, the work stand 106 is a first or entry work stand 106 of the rolling mill 104, and the optical sensor 108 is provided upstream from the first work stand 106. However, in other embodiments, the optical sensor 108 may be provided relative to other work stands 106 as desired, including at various interstand locations. As discussed in detail below, based on visual data from the optical sensor 108, the strip position of the metal strip 102 may be determined, and a control response for the rolling mill 104 may be determined, provided, and/or implemented based on the determined strip position of the metal strip 102.

**[0019]** The optical sensors 108 may be various devices suitable for obtaining the at least one image of at least a portion of the metal strip 102, such as but not limited to various cameras and/or video cameras for capturing the at least one image as a single frame, video, and/or as otherwise desired. As non-limiting examples, the optical sensors 108 may include optical or video cameras, single or multi-stereo cameras, laser-based cameras, thermal (e.g., infrared) cameras, visible light cameras, red-green-blue depth (RGB-D) cameras, combinations thereof, and/or other devices as desired. In certain embodiments, the optical sensors 108 may be visible spectrum cameras. In some embodiments, the type of optical sensor 108 utilized may depend on an environment of the metal processing system 100 in which the optical sensor 108 is installed. As non-limiting examples, a visible spectrum camera may be provided in an environment of the metal processing system 100 with a controlled background and good visibility (e.g., due to minimized or reduced fumes), a thermal camera may be provided in an environment with poor visibility (e.g., due to moderate or increased fumes) and a controlled background, and a laser-based camera may be provided in an environment with poor visibility and a complex background. In other embodiments, the various types of optical sensors 108 may be utilized in environments as desired.

**[0020]** Any number of optical sensors 108 may be utilized as desired. As best illustrated in FIG. 2, the metal processing system 100 illustrated includes two optical sensors 108A-B; however, in other embodiments, the metal processing system 100 may include a single optical sensor 108, two optical sensors 108, three optical sensors 108, etc.

**[0021]** The optical sensors 108 may be provided at various angles, orientations, etc. within the metal processing system and relative to the passline 103. In certain embodiments, the optical sensors 108 are positioned to capture at least one image of a portion of the metal strip 102. In certain embodiments, the optical sensors 108 are positioned to capture at least a portion of an edge of the metal strip 102. Optionally, the optical sensors 108 are positioned such that portions of the metal strip 102 may be determined in at least two directions or axes as discussed in detail below.

**[0022]** In embodiments where a plurality of optical sensors 108 are provided, the type of optical sensor 108 and/or the arrangement of the optical sensors 108 within the metal processing system 100 may be the same or different as desired. As a non-limiting example and referring to FIG. 2, the optical sensors 108A-B are arranged above the metal strip 102 and/or the passline 103 such that the optical sensor 108A has a first detection region 126 that includes a first edge 128 of the metal strip 102 and the optical sensor 108B has a second detection region 130 that includes a second edge 132 of the metal strip 102. In certain embodiments, the one or more optical sensors 108 optionally may detect the edges 128, 132 in at least two axes or directions (e.g., in a width direction and in a height direction). As another non-limiting example, the metal processing system 100 may include three optical sensors 108, of which a first optical sensor 108 is a visible spectrum camera, a second optical sensor 108 is a laser-based camera, and a third optical sensor 108 is a thermal camera. As another non-limiting example, the metal processing system 100 may include two visible spectrum cameras as optical sensors 108, each of which is oriented at a different angle relative to the metal strip 102 and/or the passline 103 for capturing different portions of the metal strip 102. As yet another non-limiting example, the metal processing system 100 may include a first optical sensor 108 above the passline 103 and a second optical sensor 108 below the passline 103. Various other arrangements and/or combinations of optical sensors 108 may be utilized as desired.

**[0023]** As mentioned, the controller 110 may include one or more processing units and/or one or more memory devices. The processing unit may be various suitable processing devices or combinations of devices including but not limited to one or more application specific integrated circuits, digital signal processors, digital signal processing devices, programmable logic devices, field programmable gate arrays, processors, controllers, micro-controllers, microprocessors, other electronic units, and/or a combination thereof. The one or more memory devices may be any machine-readable medium that can be accessed by the processor, including but not limited to any type of long term, short term, volatile, nonvolatile, or other storage medium, and is not to be limited to any particular type of memory or number of memories, or type of media upon which memory is stored. Moreover, as disclosed herein, the term “storage medium,” “storage” or “memory” can represent one or more memories for storing data, including read only memory (ROM), random access memory (RAM), magnetic RAM, core memory, magnetic disk storage mediums, optical storage mediums, flash memory devices and/or other machine readable mediums for storing information. The term “machine-readable medium” includes, but is not limited to, portable or fixed storage devices, optical storage devices, wireless channels, and/or various other storage mediums capable of storing that contain or carry instruction(s) and/or data. In certain embodiments, the controller 110 optionally includes an associated user interface, including but not limited to a graphical user interface or a human machine interface, such that the controller 110 may obtain information from a user and/or provide information to the user. In such embodiments, the user interface and/or human machine interface may be on the controller 110 itself or may be at a location remote from the controller 110.

**[0024]** The controller 110 may be communicatively coupled to the one or more optical sensors 108 such that the controller 110 receives the visual data from the one or more optical sensors 108. Communication between the controller 110 and the one or more optical sensors 108 may be various types of communication as desired, such as but not limited to wired communication and/or wireless communication (e.g., near field, cellular, Wi-Fi, Bluetooth®, Bluetooth Low Energy, etc.).

**[0025]** In various embodiments, the controller 110 may determine a strip position of the metal strip 102 based on the visual data from the one or more optical sensors 108. The strip position may be determined using various techniques as desired. As one non-limiting example, the controller 110 may determine the strip position based on a detection of the edges 128, 132 of the metal strip 102. In such embodiments, the edges 128, 132 may be detected using various techniques and/or based on the type of visual data and/or the type of optical sensor 108. As non-limiting examples, the edges 128, 132 may be detected based on a difference in contrast between the metal strip 102 and background information, a difference in texture properties between the metal strip 102 and background information, a difference in color or color properties, a detected movement, reflectivity properties, combinations thereof, and/or other techniques as desired. As a non-limiting example, if the optical sensor 108 is a visible spectrum camera, the edges 128, 132 may be detected based on a contrast difference between the metal strip 102 and equipment of the metal processing system 100. Optionally, the edges 128, 132 are detected using a calibration point or feature of the metal processing system 100, such as but not limited to a slot, indicator, and/or other identifiable feature in the visual data. As another non-limiting example, if the optical sensor 108 is a thermal camera, the edges 128, 132 may be detected based on a temperature difference between the metal strip 102 and background equipment (represented by different colors or as otherwise desired). In certain embodiments, the strip position may be determined in at least two axes or directions. As a non-limiting example, the strip position may be determined in a width (or horizontal) direction and a height (or vertical) direction.

**[0026]** In certain embodiments, the controller 110 may utilize the determined strip position to generate and/or send instructions for performing one or more control responses. As one non-limiting example, the controller 110 may determine a strip width of the metal strip 102 based on a distance between the detected edges 128, 132 as the control response. As another non-limiting example, the controller 110 may determine a position of portions of the metal strip 102, such as but not limited to positions of the edges 128, 132 relative to the rolling mill 104 and/or the passline 103 and/or a position of a strip center (e.g., halfway between the edges 128, 132) relative to the rolling mill 104 and/or the passline 103 as the control response.

**[0027]** In some embodiments, the controller 110 may utilize the detected edges 128, 132 and/or the determined strip width and/or the determined strip position to control various components and/or actuators of the metal processing system 100 and/or generate an output response to an operator based on the measured strip position.

**[0028]** As one non-limiting example, the controller 110 may control a strip centralization actuator of the metal processing system 100. In such embodiments, the control may be based on a difference between a desired position of the strip center and the measured position of the strip center (hereinafter "measured off-center"). In some embodiments, the controller 110 may display or otherwise provide the measured off-center to the operator on a user interface. In such embodiments, the operator optionally may manually center the metal strip 102. In certain embodiments, manually centering of the metal strip 102 may be performed at reduced rolling speeds, such as but not limited to during start-up and/or at rolling speeds less than or equal to 300 m/min. Additionally, or alternatively, the controller 110 may control one or more strip centralization actuators such as but not limited to a roller, entry mandrel, or other suitable strip centralization actuators as desired. Optionally, the controller 110 may control the strip centralization actuator to center the strip based on the measured off-center being within a threshold limit. As a non-limiting example, the controller 110 may control the strip centralization actuators to control the position of the metal strip 102 based on the measured off-center being less than or equal to 20 mm. In other embodiments, other threshold limits may be utilized as desired. In certain embodiments, automatic centering of the metal strip 102 utilizing the strip centralization actuators may be performed at various stages of rolling (e.g., start-up, steady state, tail-out, etc.).

**[0029]** In certain embodiments, the controller 110 may further control a profile control actuator and/or flatness control actuator of the metal processing system 100 after the metal strip 102 is centered. As non-limiting examples, the controller 110 may control actuators such as but not limited to roll bending, shifting, tilt angle, etc. in the rolling mill 104. In various embodiments, controlling the profile and/or flatness after centering based on the measured strip position may allow for the metal strip 102 to have an improved and/or desired profile for subsequent processing, a customer, etc.

**[0030]** In some embodiments, the controller 110 may control a tension actuator of the metal processing system 100 after the metal strip 102 is centered. As non-limiting examples, the controller 110 may control the unwind coiler 118, the rewind coiler 120, and/or other tensioning actuator as desired. In various embodiments, controlling tension actuators after the metal strip 102 is centered may allow for improved edge tension control and/or edge tension symmetry, which in turn may reduce strip breakage rates due to asymmetrical edge tension.

**[0031]** As another non-limiting example, the controller 110 may control a steering actuator of the metal processing system 100 and/or generate an output response based on the measured strip position. In such embodiments, the measured strip position may include the measured strip position in at least two axes – e.g., in a height direction and in a width direction. In such embodiments, the measured strip position in the height direction may indicate bounce (or change in vertical height) during rolling, and the steering actuator may be controlled to minimize the bounce and thereby reduce the risk of cobble in the metal strip 102. Additionally, or alternatively, the steering actuator may be controlled based on the measured strip position to improve thread-in of the metal strip 102 into the rolling mill 104 (e.g., guiding a leading edge of the metal strip 102 to the rolling mill 104) and/or to improve tail-out of the metal strip 102 (e.g., guiding a tail edge of the metal strip 102 to the rolling mill 104).

**[0032]** The above examples are for illustrative purposes, and in other embodiments, the measured strip position of the metal strip 102 based on the visual data from the one or more optical sensors 108 may be utilized for control of various other components and/or processes of the metal processing system 100 as desired.

**[0033]** FIG. 3 illustrates an example of a method for processing the metal strip 102 with the metal processing system 100.

**[0034]** In a block 302, the method includes receiving, by the controller 110, the visual data from the one or more optical sensors 108. Block 302 may include receiving visual data from a plurality of optical sensors 108, of which the optical sensors 108 may be various types of optical sensors 108 and/or at various arrangements relative to the passline 103.

**[0035]** In a block 304, the method includes determining the strip position of the metal strip 102 in the rolling mill 104 and/or the metal processing system 100 based on the visual data. In certain embodiments, block 304 may include determining the one or more edges 128, 132 of the metal strip 102 in one or more images from the optical sensors 108. In various embodiments, determining the one or more edges 128, 132 may include determining the edges based on contrast, texture properties, color properties, relative movement, reflectivity, combinations thereof, and/or other techniques as desired.

**[0036]** In a block 306, the method may include generating a control response based on the determined strip position. In some embodiments, block 306 may include generating an output to the operator on a user interface and/or remote device. As non-limiting examples, block 306 may include generating at least one of an audible alert or alarm or a visual alert or alarm for the operator based on the determined strip position. In some embodiments, block 306 may include determining a strip width based on the measured strip position. In certain embodiments, block 306 may include controlling one or more of a strip centralization actuator, a flatness control actuator, a profile control actuator, a steering actuator, and/or a tension actuator. Block 306 may include determining, by the controller 110, that operating parameters of the rolling mill 104 or metal processing system 100 are maintained and/or unchanged.

**[0037]** Various other control responses for the metal processing system 100 and/or the rolling mill 104 based on the measured strip position of the metal strip 102. Moreover, various other processes may utilize the measured strip position as desired.

**[0038]** A collection of exemplary embodiments is provided below, including at least some explicitly enumerated as an "Illustration" providing additional description of a variety of example embodiments in accordance with the concepts described herein. These illustrations are not meant to be mutually exclusive, exhaustive, or restrictive; and the disclosure not limited to these example illustrations but rather encompasses all possible modifications and variations within the scope of the issued claims and their equivalents.

**[0039]** Illustration 1. A rolling system for a metal strip, the rolling system comprising: a rolling mill comprising at least one work stand configured to receive the metal strip; an optical sensor; and a controller operably connected to the optical sensor and the rolling mill, the controller configured to: determine a strip position of the metal strip relative to the at least one work stand based on visual data from the optical sensor; and generate a control response for the rolling mill based on the determined strip position.

**[0040]** Illustration 2. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to determine the strip position by identifying an edge of the metal strip in the visual data from the optical sensor; and measuring a strip position in the rolling mill based on the identification of the edge.

**[0041]** Illustration 3. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to generate at least one of an audible alert or alarm or a visual alert or alarm as the control response.

**[0042]** Illustration 4. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to control a strip centralization actuator of the rolling mill and center the metal strip at the work stand as the control response.

**[0043]** Illustration 5. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is further configured to control a flatness control actuator after centering the metal strip.

**[0044]** Illustration 6. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to control a steering actuator of the rolling mill for controlling steering of the metal strip during thread in or tail out as the control response.

**[0045]** Illustration 7. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the optical sensor comprises at least one of a laser-based camera, a thermal camera, or a visible light camera, an optical camera, a video camera, or an RGB-D camera.

**[0046]** Illustration 8. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to control a tension actuator of the rolling mill for controlling edge tension in the metal strip as the control response.

**[0047]** Illustration 9. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to measure a strip width of the metal strip as the control response.

**[0048]** Illustration 10. The rolling system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is further configured to control a flatness control actuator based on the measured strip width of the metal strip.

**[0049]** Illustration 11. A metal processing system for receiving a metal strip, the metal processing system comprising: a camera positioned to capture at least one image of a portion of the metal strip; and a controller communicatively coupled to the camera, wherein the controller is configured to: acquire the at least one image of the portion of the metal strip from the camera; determine an edge of the metal strip in the at least one image; determine a strip position of the metal strip based on the determined edge of the metal strip; and generate a control response for a rolling mill based on the determined strip position.

**[0050]** Illustration 12. The metal processing system of any preceding or subsequent illustration or combination of illustrations, wherein the camera comprises at least one of a laser-based camera, a thermal camera, or a visible light camera, an optical camera, a video camera, or an RGB-D camera.

**[0051]** Illustration 13. The metal processing system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to generate at least one of an audible alert or alarm or a visual alert or alarm as the control response.

**[0052]** Illustration 14. The metal processing system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to control a strip centralization actuator of the rolling mill and center the metal strip at a work stand as the control response.

**[0053]** Illustration 15. The metal processing system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to control a flatness control actuator of the rolling mill as the control response.

**[0054]** Illustration 16. The metal processing system of any preceding or subsequent illustration or combination of illustrations, wherein the controller is configured to control a steering actuator of the rolling mill for controlling steering of the metal strip during thread in or tail out as the control response.

**[0055]** Illustration 17. A method of processing a metal strip, the method comprising: receiving visual data from at least one camera of a portion of the metal strip being processed by a rolling mill; identifying an edge of the metal strip in the visual data; determining a strip position in the rolling mill based on the identification of the edge; and generating a control response for the rolling mill based on the determined strip position.

**[0056]** Illustration 18. The method of any preceding or subsequent illustration or combination of illustrations, wherein generating the control response comprises generating at least one of an audible alert or alarm or a visual alert or alarm.

**[0057]** Illustration 19. The method of any preceding or subsequent illustration or combination of illustrations, wherein generating the control response comprises controlling a strip centralization actuator of the rolling mill and centering the metal strip at a work stand of the rolling mill.

**[0058]** Illustration 20. The method of any preceding or subsequent illustration or combination of illustrations, wherein generating the control response comprises controlling a steering actuator of the rolling mill for controlling steering of the metal strip during thread in or tail out of the metal strip.

**[0059]** The subject matter of embodiments of the present disclosure is described here with specificity to meet statutory requirements, but this description is not necessarily intended to limit the scope of the claims. The claimed subject matter may be embodied in other ways, may include different elements or steps, and may be used in conjunction with other existing or future technologies. This description should not be interpreted as implying any particular order or arrangement among or between various steps or elements except when the order of individual steps or arrangement of elements is explicitly described. Directional references such as "up," "down," "top," "bottom," "left," "right," "vertical," "horizontal," "lateral," "longitudinal," "front," and "back," among others, are intended to refer to the orientation as illustrated and described in the figure (or figures) to which the components and directions are referencing.

**[0060]** The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, or gradients thereof, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate embodiments of the invention, and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

**[0061]** The above-described aspects are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the present disclosure. Many variations and modifications can be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the present disclosure. All such modifications and variations are intended to be included herein within the scope of the present disclosure, and all possible claims to individual aspects or combinations of elements or steps are intended to be supported by the present disclosure. Moreover, although specific terms are employed herein, as well as in the claims that follow, they are used only in a generic and descriptive sense, and not for the purposes of limiting the described embodiments, nor the claims that follow.

## CLAIMS

That which is claimed:

1. A rolling system for a metal strip, the rolling system comprising:
a rolling mill comprising at least one work stand configured to receive the metal strip;
an optical sensor; and
a controller operably connected to the optical sensor and the rolling mill, wherein the controller is configured to:
determine a strip position of the metal strip relative to the at least one work stand based on visual data from the optical sensor; and
generate a control response for the rolling mill based on the determined strip position.

2. The rolling system of claim 1, wherein the controller is configured to determine the strip position by:
identifying an edge of the metal strip in the visual data from the optical sensor; and
measuring a strip position in the rolling mill based on the identification of the edge.

3. The rolling system of claim 1, wherein the controller is configured to generate at least one of an audible alert or alarm or a visual alert or alarm as the control response.

4. The rolling system of claim 1, wherein the controller is configured to control a strip centralization actuator of the rolling mill and center the metal strip at the work stand as the control response.

5. The rolling system of claim 4, wherein the controller is further configured to control a flatness control actuator after centering the metal strip.

6. The rolling system of claim 1, wherein the controller is configured to control a steering actuator of the rolling mill for controlling steering of the metal strip during thread in or tail out as the control response.

7. The rolling system of claim 1, wherein the optical sensor comprises at least one of a laser-based camera, a thermal camera, a visible light camera, an optical camera, a video camera, or an RGB-D camera.

8. The rolling system of claim 1, wherein the controller is configured to control a tension actuator of the rolling mill for controlling edge tension in the metal strip as the control response.

9. The rolling system of claim 1, wherein the controller is configured to measure a strip width of the metal strip as the control response.

10. The rolling system of claim 9, wherein the controller is further configured to control a flatness control actuator based on the measured strip width of the metal strip.

11. A metal processing system for a metal strip, the metal processing system comprising:

a camera positioned to capture at least one image of at least a portion of the metal strip; and

a controller communicatively coupled to the camera, wherein the controller is configured to:

acquire the at least one image of the at least a portion of the metal strip from the camera;

determine an edge of the metal strip in the at least one image;

determine a strip position of the metal strip based on the determined edge of the metal strip; and

generate a control response for a rolling mill based on the determined strip position.

12. The metal processing system of claim 11, wherein the camera comprises at least one of a laser-based camera, a thermal camera, a visible light camera, an optical camera, a video camera, or an RGB-D camera.

13. The metal processing system of claim 11, wherein the controller is configured to generate at least one of an audible alert or alarm or a visual alert or alarm as the control response.

14. The metal processing system of claim 11, wherein the controller is configured to control a strip centralization actuator of the rolling mill and center the metal strip at a work stand as the control response.

15. The metal processing system of claim 11, wherein the controller is configured to control a flatness control actuator of the rolling mill as the control response.

16. The metal processing system of claim 11, wherein the controller is configured to control a steering actuator of the rolling mill for controlling steering of the metal strip during thread in or tail out as the control response.

17. A method of processing a metal strip, the method comprising:
receiving visual data from at least one camera of at least a portion of the metal strip being processed by a rolling mill;
identifying an edge of the metal strip in the visual data;
determining a strip position in the rolling mill based on the identification of the edge; and
generating a control response for the rolling mill based on the determined strip position.

18. The method of claim 17, wherein generating the control response comprises generating at least one of an audible alert or alarm or a visual alert or alarm.

19. The method of claim 17, wherein generating the control response comprises controlling a strip centralization actuator of the rolling mill and centering the metal strip at a work stand of the rolling mill.

20. The method of claim 17, wherein generating the control response comprises controlling a steering actuator of the rolling mill for controlling steering of the metal strip during thread in or tail out of the metal strip.

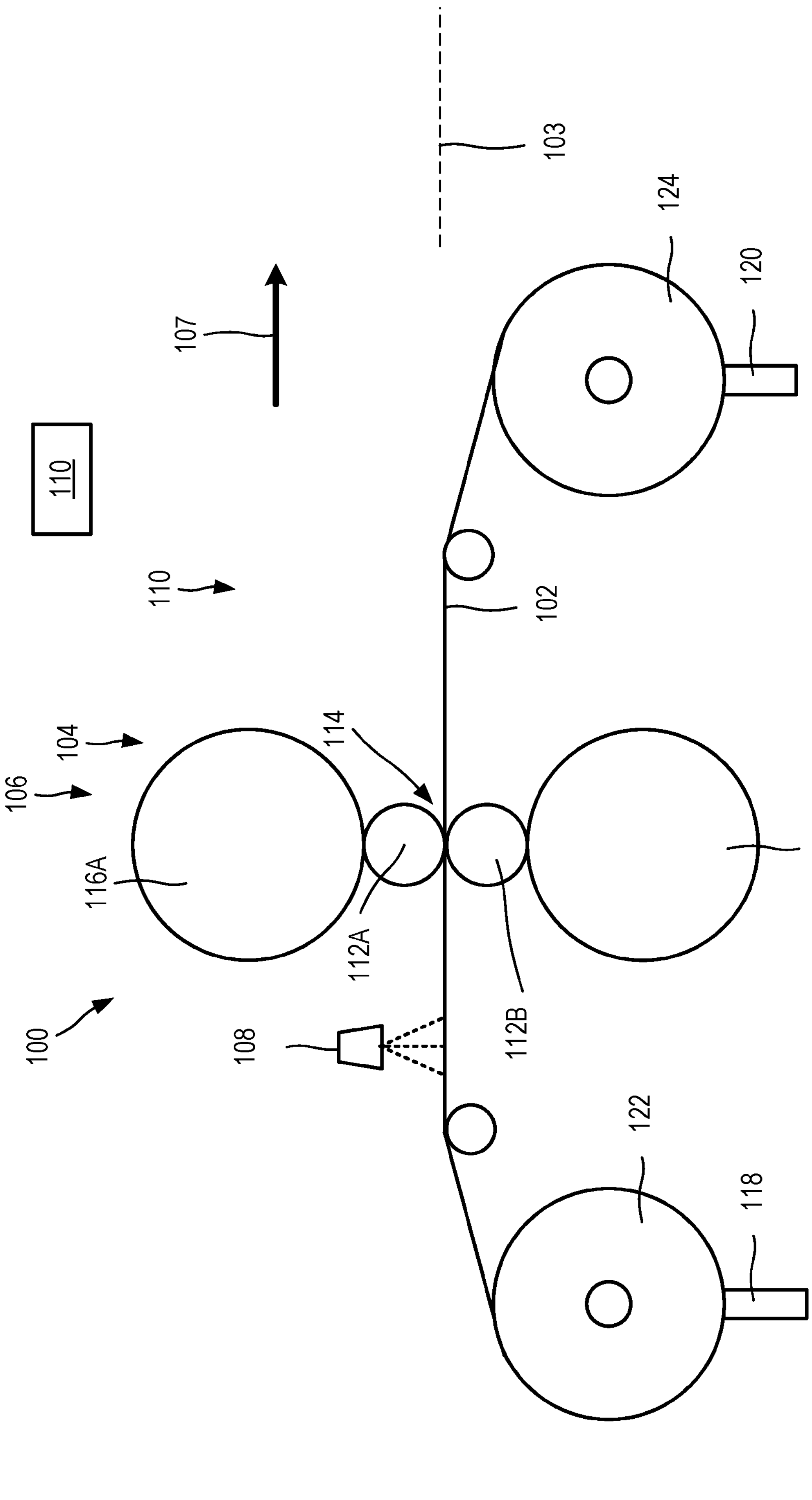
103
124
120
107
110
110
102
104
114
106
116A
112A
116B
112B
100
108
122
118

FIG. 1

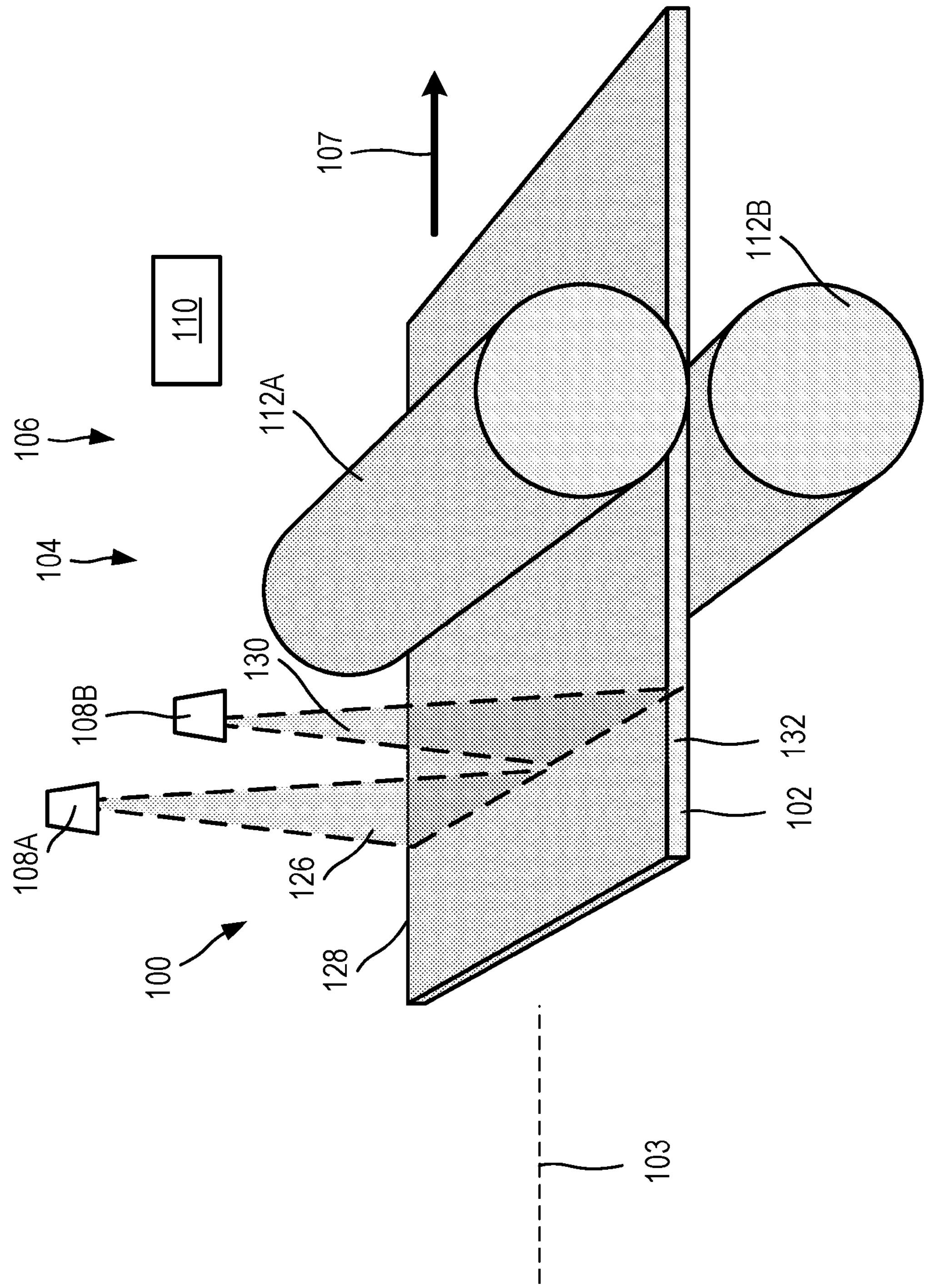


FIG. 2

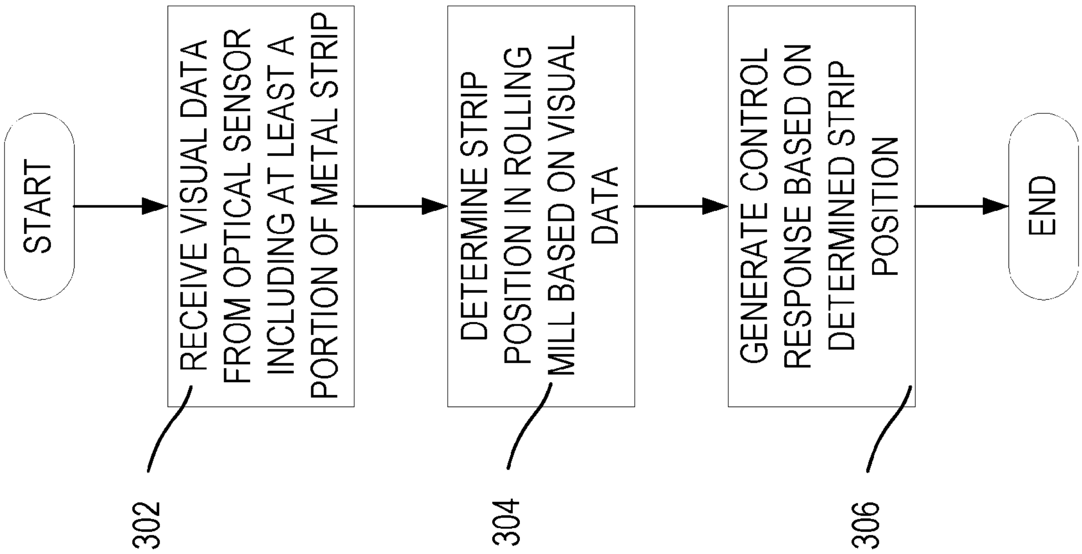
START
RECEIVE VISUAL DATA FROM OPTICAL SENSOR INCLUDING AT LEAST A PORTION OF METAL STRIP
302
DETERMINE STRIP POSITION IN ROLLING MILL BASED ON VISUAL DATA
304
GENERATE CONTROL RESPONSE BASED ON DETERMINED STRIP POSITION
306
END

FIG. 3

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/038199

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. B21B37/68 B21B38/00 B21C51/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
B21B B21C B21L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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[X] Further documents are listed in the continuation of Box C.  [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 27 September 2024 | 10/10/2024 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Forciniti, Marco |

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| International application No |
|---|
| PCT/US2024/038199 |

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International application No
PCT/US2024/038199

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