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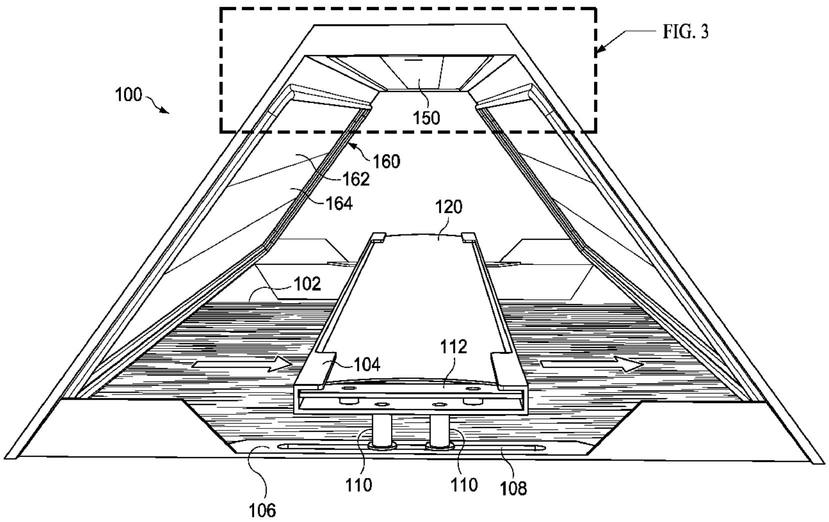
[Continued on next page]

(54) **Title**: CALIBRATION OF A DYNAMIC DIGITAL IMAGING SYSTEM FOR DETECTING DEFECTS IN PRODUCTION STREAM

FIG. 1



(57) **Abstract**: A system and method for calibrating a dynamic digital imaging system for the detection of defects in a moving product stream. The system has an elevated platform above a conveying unit for receiving a reference color tile. The elevated platform allows for the passage of products to be inspected on the below conveying unit surface such that calibration and re-calibration processes during image capturing may be accomplished on a continuous basis without interruption of the product stream.

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Calibration of a Dynamic Digital Imaging System For Detecting Defects in Production Stream

Technical Field

[0001] The present invention relates in general to digital image analysis, and more particularly to calibration of a dynamic digital imaging system for detecting anomalies or defects in digital images of continuously moving production streams.

Background

[0002] Use of image analysis in detection of anomalies or defects has been in use in various fields. Specifically, the food processing industry has incorporated digital image analysis in conjunction with continuous conveyors in automated food sorting systems. For example, some prior art methods provide for the inspection of food products and other products or items whose quality can be visually ascertained. As with any advanced imaging or spectral analysis, the detected images need to be compared against a reference, meaning that the system needs to be calibrated to ensure consistent measurements. Yet the systems and methods known in the art of image analysis often require calibration procedures that interrupt the capturing of images for defect detection. This can be problematic when the defect detection system is in use in conjunction with continuous production lines (e.g., continuous conveyor systems transporting products to be inspected for defect).

[0003] Therefore, a need exists for a system and method that provides for calibration and recalibration of a digital defect detection system, that does not require slowing down or stopping the production conveyor system. Further, an improved digital defect detection system needs to be capable of retrofitting an existing product conveyor system. Finally, a need exists for the digital defect detection system and method that provide accurate and real-time calibration of the image acquisition and analysis systems during continuous production.

SUMMARY

[0004] In accordance with one aspect of the present invention, a method for calibrating a dynamic digital imaging system for detecting defects in a production stream is provided that substantially eliminates or reduces disadvantages associated with previous methods of static calibration. The method, in one embodiment, includes the steps of (a) placing a calibration color tile on a platform elevated above the conveyor in the field of view of a camera; (b) obtaining light absorption data of the calibration color; (c) calculating a component color intensity of the light absorption data of the calibration color; (d) normalizing the component color intensities of the calibration color; (e) removing the platform out of the field of view of the camera; (f) obtaining light absorption data of the products; (g) calculating a component color intensity of the light absorption data of the products; (h) normalizing the component color intensities of the products; and (i) calculating a quality index score of the products based on the component color intensities of the calibration color and the products.

[0005] In accordance with another aspect of the present invention, a system for calibrating a dynamic digital imaging system for detecting defects in production stream is disclosed. In some embodiments, the system includes a conveyor unit having a first frame extending along at least a portion of a width of the conveyor unit; a platform elevated above the conveyor unit on at least one support movably coupled to a track within the first frame; and a slot within the platform for receiving a color tile comprising a plurality of reference color segments. Some embodiments also include a second frame coupled to the first frame directly across the width of the conveyor unit; an imaging unit comprising a camera having a field of view, a camera window, and a control/data line; and/or a control unit comprising a processor, a memory, and a display device wherein further the imaging unit is in communication with the control unit through the control/data line.

[0006] Certain embodiments of the present invention may provide a number of technical advantages. For example, according to one embodiment of the present invention, the digital imaging system can be calibrated substantially simultaneously as the subjects move along a conveyor system. Yet another technical advantage associated with one embodiment of the present invention is its versatility. The features provided by the present invention may be applied to any conveyor systems for production of materials that require quality assurance. While the embodiments described herein use the example of food product conveyor system, the systems and methods in this disclosure are easily adaptable to any continuous production context. Without being limiting, some examples of the type of industry and application of the disclosed method and system include: baked confectionary goods, savory snack food, candies (e.g., jelly beans, chocolates, candy coated chocolates, taffy, and colored gummy snacks), wood products, paper products, textiles, and many more.

[0007] Certain embodiments of the present invention may enjoy some or all of these advantages. Other technical advantages may be readily apparent to one skilled in the art from the following figures, description, and claims.

BRIEF DESCRIPTION

[0008] For a more complete understanding of the present invention and its advantages, reference is made to the following description, and the accompanying drawings, in which:

[0009] **FIG. 1** illustrates a perspective view of a system for calibrating a dynamic digital imaging system for detecting defects in production stream according to a particular embodiment.

[00010] **FIG. 2** illustrates a perspective view of a system for calibrating a dynamic digital imaging system for detecting defects in production stream according to a particular embodiment.

[00011] **FIG. 3** illustrates a perspective view of a system for calibrating a dynamic digital imaging system for detecting defects in production stream according to a particular embodiment.

[00012] **FIG. 4** illustrates a flow chart of a method for calibrating a dynamic digital imaging system for detecting defects in production stream according to a particular embodiment.

[00013] **FIG. 5A** and **5B** illustrate exemplar line scans of calibration reference unit at the conveyor belt height and at an elevated height, respectively, according to one embodiment.

[00014] **FIG. 6A** and **6B** illustrate exemplar line scan raw data and the normalized plot, respectively, according to one embodiment.

[00015] **FIG. 7** illustrates a perspective view of a system for calibrating a dynamic digital imaging system for detecting defects in production stream according to an alternative embodiment.

[00016] **FIG. 8** illustrates a top view of a system for calibrating a dynamic digital imaging system for detecting defects in production stream according to an alternative embodiment.

Detailed Description

[00017] **Figure 1** illustrates a dynamic digital imaging system for detecting defects in production stream according to some embodiments. As used herein, the term “dynamic digital imaging system” refers to any system operable to obtain digital image of continuously moving subjects (e.g., continuously moving production stream). System **100** includes a control unit, a conveyor unit, a calibration reference unit, a lighting unit, and an imaging unit. Each unit is described in further detail below.

[00018] In at least one embodiment, the control unit is a computer having a processor, a memory, a display device (e.g., a monitor), and an input device (e.g., keyboard, mouse, or touchpad). In some embodiments, the control unit is also equipped with a network interface and is connected to a network. Such embodiment provides an advantage of the ability to control the system **100** at a remote location. In some embodiments, the control unit controls the conveyor unit, the calibration reference unit, the lighting unit **160**, and the imaging unit. In other embodiments, the conveyor unit is controlled separately by an operator or another system. As will be discussed in further detail below, the calibration reference unit may also be manually controlled by an operator. In some embodiments, the lighting unit **160** and the imaging unit are controlled by separate systems in communication with each other. Still in another embodiment, an operator manually adjusts the light source **162** intensity based on the data from the captured image. In an alternative embodiment, the lighting unit **160** is a static unit, and the control unit adjusts the light intensity data by applying a scaling factor.

[00019] In some embodiments, the conveyor unit is a conveyor belt **102**. In other embodiments, the conveyor unit is any system capable of supporting and transporting a continuous stream of products. In some embodiments, the imaging, lighting, and reference color units are housed in a portable enclosure (as shown in **Figure 1**) that can be moved away from conveyor belt **102** to another location along the production stream. This portable enclosure provides an advantage of easily retrofitting an existing conveyor system.

[00020] In one embodiment as shown in **Figure 1**, the calibration reference unit comprises a platform **104**, a frame **106**, a track **108**, support posts **110**, a slot **112** along the platform **104**, and one or more color tiles **120**. It should be noted that while the embodiment of **Figure 1** depicts two support posts **110**, in one embodiment, the calibration reference unit comprises only one support post **110**. Thus, generally, the calibration reference unit comprises at least one support post **110**. In one embodiment, shown more closely in **Figure 2**, the platform **104** is supported by frame **106** having a track **108** in which the support posts **110** are free to slide. In such embodiment, the calibration reference unit may move in a direction perpendicular or parallel to the movement of the conveyor belt **102**. This may allow the calibration reference unit to be moved into or out of the field of view of the imaging unit as needed. For example, when the system **100** is not in a calibration sequence, the support posts **110** of calibration reference unit slide along the track **108** out of the field of view of the imaging unit in the direction parallel to the movement of the conveyor belt so that the imaging unit can capture images of the product stream on the conveyor belt **102**. Conversely, when the system **100** is in calibration or recalibration mode, the calibration reference unit slides into the field of view of the imaging unit. In some embodiments, the operator of the system **100** manually moves the calibration reference unit into or out of the field of view, whereas in other embodiments the control unit automatically moves it depending on whether the system **100** is in a calibration mode or detection mode. While **Figure 1** illustrates simple support posts **110** sliding along the track **108**, any mechanism capable of moving calibration reference unit in and out of the field of view of the imaging unit can be substituted. Some examples include rollers, casters, wheels, magnetic tracks, or more sophisticated robotic controls.

[00021] Generally, the platform **104** may comprise a definable height such that it is raised above the conveyor belt **102** with one or more support posts **110** or suitable substitute thereof. The height of the support posts **110** can be adjusted, for example, according to the size and shape of the products being transported on the conveyor belt **102**. In one embodiment, the support posts **110** are tall enough to provide at least about a three-inch (about 7 or 8 cm) clearance between the conveyor belt **102** surface and the bottom of the platform **104**. This can be advantageous in that calibration of the system **100** can occur without interrupting the continuous flow of the product stream.

[00022] The platform **104** has a slot **112** in which one or more color tiles **120** can slide and be supported. The color tiles **120** can be a single tile of one color, a single tile with multiple colors, or multiple tiles of various colors. The color tiles **120** are made of any suitable material, including paper, polymer (including ultra-high molecular weight polyethylene, acrylonitrile butadiene styrene (ABS), polyoxymethylene, nylon, polytetrafluoroethylene, etc.), metal, ceramic, composite, or wood. The size of the color tiles **120** may also vary depending on the needs of the imaging unit. In one embodiment, the color tile **120** comprises the same width as the width of the conveyor belt **102**, and is disposed perpendicular to the flow of the product stream on the conveyor belt **102**. In the particular embodiment shown in **Figure 1**, the color tile **120** is about 48 inches (about 122 cm) wide and between about 6 to about 8 inches (about 15 to about 20 cm) long. In one embodiment, when sliding a color tile perpendicularly to the direction of conveyor belt travel, a color tile may be relatively small because the individual pixel size is on the order of 0.023 inch square. To prevent interference with light reflected from surrounding areas, smaller color tile is preferred in one embodiment. Another advantage of using smaller color tiles is the flexibility to use smaller and lighter weight support mechanisms. In some embodiments, the size range of the color tile ranges from about 0.1 inch to about 0.25 inch square. It should be noted that

with smaller tiles, the support mechanism should be virtually "invisible" to the imaging unit as it has opportunity to influence local lighting in the region of the tile. In another embodiment, a color tile **120** of a narrower width runs parallel to the direction of the conveyor belt **102**. In one embodiment, a color tile **120** may slide perpendicular to the direction of the conveyor belt. In another embodiment, a color tile **120** may further slide parallel to the direction of the conveyor. In some embodiments, the color tile is capable of both perpendicular and parallel movements relative to the direction of product flow on the conveyor belt. In some embodiments, color tiles **120** may comprise a matte finish, thereby avoiding the presence of a glare surrounding the light source or lighting when its surface is illuminated. Alternatively, in one embodiment, the lighting source may comprise a reflective strip or reflector **164** along the length of the calibration reference unit.

[00023] The lighting unit **160** (best depicted in **Figure 1**) includes a light source **162** and optionally includes a reflector **164**. The light source **162** may be any suitable source of light capable of sufficiently illuminating the reference calibration unit and the product stream on the conveyor unit **102**. Some examples of suitable light source include incandescence (e.g., conventional incandescence bulb or a halogen lamp), electroluminescence (e.g., light emitting diodes (LEDs)), fluorescence (e.g., compact fluorescent lamps or a plasma lamp), high-intensity discharge lamp, arc lamp, etc. In one embodiment, the lighting unit **160** is affixed on the side walls of the system **100** enclosure as shown in **Figure 1**. The walls are angled in one embodiment as depicted in the figures so as to not cast a shadow or a glare on the imaging subject during image capturing. Because the product stream on the conveyor **102** and the calibration reference unit are at a different height relative to the light source, a fixed lighting unit may cast a shadow or glare at one height but not the other. The reflector **164** alleviates any shadow or glare issue by redirecting the light. The reflector **164** is any suitable device capable of reflecting light, such as a mirror or a metal surface. The reflector **164**

surface need not be polished as it is sufficient that it be opaque and reflective of "white" light in some embodiments. In other embodiments, e.g., where a specific color measurement is being made, a reflector **164** that selectively absorbs undesirable light wavelengths is used. In other embodiments where fluorescence is measured, the reflector **164** might take one wavelength of light and transpose it to a preferred wavelength that would then be detectable. For the foregoing examples, color tiles **120** of specific properties that would mimic the feature being measured may be needed. The color tiles **120** as well as the reflector **164** could be designed and fabricated, for example, by using semiconductor-like techniques known in the art for doping a substrate with chemicals that exhibit desirable properties.

[00024] In some embodiments, both or either the reflector **164** and the whole lighting unit **160** are actuated by the control unit. It should be noted that the height difference between the conveyor belt **102** and the calibration reference unit also poses an issue of light intensity difference. The light source **162** being generally above the subject to be illuminated, the calibration reference unit receives higher intensity of light than the product stream below the unit on the conveyor belt **102**. Thus, in some embodiments, the control unit adjusts the output intensity of the light source **162** depending on whether the system **100** is in calibration mode or detection mode. In other embodiments, the lighting intensity is calculated and corrected based on the relationship between the intensity and the distance from the emitting source. Such relationship can be determined theoretically or empirically and then integrated into the calibration algorithm.

[00025] **Figure 3** illustrates a close-up of one embodiment of the imaging unit. The imaging unit includes a camera window **150**, a line scan camera **300**, and a control/data line **350** in some embodiments. In other embodiments, the line scan camera **300** is substituted with any device capable of capturing color images of the product flow and the calibration reference unit. The imaging unit is situated generally above the imaging subject (e.g., conveyor belt **102** and the calibration reference unit). The camera window **150** is made of any optically transparent material capable of transmitting light without or with minimal loss due to absorption by the camera window **150** (e.g., glass or polymer). One of the purposes of the camera window **150** is to protect the line scan camera **300** and the control/data line **350** from the surrounding environment of the production line (e.g., dust particles) and to enable efficient cleaning.

[00026] In the particular embodiment shown in **Figures 1** through **3**, the camera window **150** extends across the width of the conveyor belt **102**. In such embodiment, the line scan camera **300** moves across the camera window **350**, and thereby captures a line image (i.e., a linear array of pixels) of the subject. The line scan camera **300** oscillates across the camera window **350** in a generally continuous manner to generate a two-dimensional image (i.e., aggregation of linear arrays of pixels). In other embodiments, the line scan camera **300** does not oscillate but rather is a linear array of adjacent sensor elements that sample the individual pixel. In one embodiment, 2,048 individual sensor elements are linearly arranged and simultaneously samples pixels 0 through 2047, respectively. This can be continuously repeated to create a continuous two-dimensional image. Such two-dimensional image can be divided into essentially four square frames of 1024×1024 pixels each for analysis in one embodiment. The size of the frames is not limited to any particular dimension, and may be adjusted according to the needs of the system. For example, in some embodiments, the frame can be as small as 2048×1 pixels or as large as limitation of the memory employed in the control unit, e.g., 2048×100,000 pixels. The image data acquired by the line scan camera **300** is transmitted through the data/control line **350** to the control unit. The data/control line **350** also actuates the movement of the line scan camera **300**. In one embodiment, the line scan camera **300** samples all 2048 pixels at the rate of about 4000 times per second. This sampling rate allows for essentially a square frame at an underlying conveyor speed of about 600 feet per minute. In embodiments where a different image capturing device is used, the movement of the camera may be obviated if the camera has sufficiently wide field of view to capture the image across the entire width of the conveyor belt **102** (e.g., wide-angle camera or a video camera). In some embodiments, the line scan camera **300** is equipped with one or more light sensors, such as charge-coupled device (CCD), reverse-biased light emitting diodes (LEDs), photodiodes, complementary metal–oxide–semiconductors (CMOS), video camera tubes (e.g., vidicon), or any other suitable image capturing device that can digitize an image and input into a digital array format inside the processor of the control unit.

[00027] **Figure 4** illustrates one embodiment of the method **400** of the system **100** in operation. Method **400** illustrates one embodiment of the calibration mode and the detection mode sequence. As used herein, the term "calibration" means the process that includes acquiring light absorption data of one or more preselected reference color, normalizing the light absorption data, and producing a set of finalized light absorption data against which the detection scan data would be referenced and compared. It should be noted that the term normalization is not interchangeable with calibration as both the calibration data set and the detection scan data set are normalized in some embodiments. As will be further explained below (in description accompanying **Figures 5A** and **5B**), normalization is generally a mathematical process in which a set of data is multiplied by a factor to reduce it to a simpler form to aid in comparison of one data set to another. In embodiments where several reference colors are scanned, the calibration process includes acquiring the light absorption data for each reference color, normalizing each set of data, and accumulating a finalized data set against which the detection scan data would be referenced and compared. Even in an embodiment where only one reference color is used, the term "calibration" is not interchangeable with "normalization" in the sense that the calibration process may also include adjustment of light source **162** (as discussed below). In embodiments where the light source **162** is adjusted from the calibration scan to the detection scan to account for the difference in light intensity at the elevated level, the term “calibration” may also encompass multiplying by a scaling factor accordingly. In other words, “normalization” generally means mathematical manipulation of one or more sets of light absorption data based on a scaling factor derived internally from that data set, whereas “calibration” generally means the entire process by which the finalized reference color light absorption data set is obtained. Referring to the embodiment depicted in **Figure 4**, the calibration mode generally includes steps **404** to **420** (and step **436** for recalibration) and the detection mode includes steps **422** to **434** (with one or more steps being optional as described further below). The normalization process can be conceptualized as adjusting the gain of each of the individual pixels of the sensor such that they respond the same way to the illumination field. For example, light at the edges of the illumination field is less intense due to the fact that there are no sources of illumination beyond the edge of the field of view (e.g., the conveyor belt). This is seen, for example, in **Figures 5A** and **5B**, which illustrate the “left” side of a line scan in one embodiment (e.g., pixels 0 through 1023 of the 2048×1 pixels frame). The intensity level starts off quite a bit lower at pixel 0 and gradually increases, but it plateaus and levels off from about pixel 512 to pixel 1023. The “right” side scan (e.g., pixels 1024 through 2047) would similarly show a fairly level intensity from pixel 1024 to about pixel 1536, and would gradually decrease in intensity as it approaches the right edge of the scan. This is referred to as a “bread loaf” effect, because the line scan looks like the top of a bread loaf. The act of normalizing addresses this phenomenon by adjusting the gain on the camera signal generated from the edge region to raise the signal level and flatten the response. A similar effect may occur within the field of view when not all the light sources **162** give off precisely the same amount of energy or even the same spectral content. Normalization in this context, then, is the act of making each pixel of the imaging device have a similar—though not precisely the same—

color response to a given stimulus. The normalization target has slightly different spectral response across its width and length, so, while normalization is an attempt to account for systematic error in the way the camera records illumination, it is only as good as the consistency of the normalization target. In one embodiment, the normalization target is a uniform color sheet of formica that is glued to a metal backing plate. Calibration, on the other hand, involves passing known colors (e.g., Munsell color tiles) through the illumination field and adjusting a color correction table to make sure that the color observed is equal to the standardized color of that tile. By introducing tiles of many colors (colors that represent the overall range of interest for the given machine) known as a gamut, it is possible to assure that, for a given color presented to the camera within the illumination field the, image will be reproduced within a degree of precision consistent with limits imposed by the variability of each step in this process.

[00028] The following paragraphs describe use of the system **100** in the context of potato chip quality assurance inspection. But it should be noted that the following description is only one example of the many variations made possible by the alternative embodiments of the system **100** as described in preceding paragraphs. System **100** is capable of use in any field or industry where it is desirable to inspect quality of the products by digital image analysis—e.g., where the appearance (color, shape, or size) of the finished product is a factor—including but not limited to food processing, consumer goods, fashion, or automobile.

[00029] Returning to the method depicted in **Figure 4**, the method **400** begins at step **402** where the scan area (i.e., imaging subject) is illuminated by activating the lighting unit **160**. At step **404**, system **100** select a color tile **120** of a certain calibration color among a predetermined or preselected set of colors. The calibration color can be any wavelength/frequency within the visible range of the electromagnetic spectrum. In one embodiment, the system **100** is equipped with a plurality of color tiles **120** ranging in numbers from two to as many as several thousands. While having a larger range of colors better enables the system **100** to calibrate the full spectrum, the operator (or the system) may choose or preselect few colors that are of high interest in the context. The reference color tiles **120** can be preselected according to the specific needs of products being inspected or to cover the full color spectrum.

[00030] At step **406**, the chosen color tile **120** is placed on an elevated platform **104**. The color tile **120** is placed on the elevated platform **104** by sliding into or engaging the slot **112**. The elevated platform **104** is moved into the field of view at step **408** via the control unit or manually by an operator. At step **410**, the line scan camera **300** captures a scan of the calibration color tile **120** and sends it to the control unit, which receives the scan data and stores it to memory. At step **412**, the processor of the control unit determines the intensity and the color components of the light absorbed by the sensors in the line scan camera **300**.

[00031] As illustrated in **Figures 5A** and **5B**, the line scan data can be visualized as a two-dimensional plot with the pixel number (the location along the linear array of pixels) on the x-axis and the light intensity level on the y-axis. The line scan data can be further broken down into the intensity levels of individual color components—such as the red, green, blue (RGB) components—at each pixel. As previously mentioned, a problem can arise when the calibration reference unit is elevated above the conveyor belt **102** because the intensity of light absorbed or reflected at each level can differ even if the same subject is scanned. For example, **Figure 5A** illustrates the color component intensity analysis of a scan of a gray color tile **120** at the conveyor belt **102** level; **Figure 5B** illustrates the same at the elevated platform **104** level. It is readily apparent that the intensity levels **Figure 5B** is much higher than that of **Figure 5A**, almost to the point of saturating the light sensors and topping out. This can cause errors when comparing the calibration data to the scans of the product flow.

[00032] Thus, returning to the general method depicted in **Figure 4**, in one embodiment, after the control unit determines intensities of the color components, the system **100** decides at step **414** whether to adjust the light source **162**. One adjustment is to increase or decrease the light source **162** intensity. In one embodiment, the control unit processor automatically adjusts the light source **162** intensity if the measured intensity is above or below a predetermined threshold. In another embodiment, the control unit processor sends an alert (e.g., via the display device) to the operator of the system **100** to adjust the light source **162** manually. Still in other embodiments, the operator of the system **100** adjusts the light source **162** intensity based on the scan observations without a prompt to do so from the control unit. Step **414** further includes adjusting the light source **162** direction in some embodiments. As seen in **Figures 5A** and **5B**, the intensity curves have much lower value at the beginning of the scan (near pixel 0) and then level off as the scan continues. This result may occur due to shadow or glare on subject surface (in this case, the gray color tile **120** or due to the bread loaf effect discussed above). In some embodiments, the control unit adjusts the angle or direction of the light source **162**, whereas the operator of the system **100** does so manually in other embodiments. After adjusting the light source **162**—whether by adjusting the intensity, direction, or both—the method **400** cycles back to step **410** to obtain a new calibration line scan. It should be noted that step **414** is optional and that the method can proceed from step **412** directly to the normalization step **416** in some embodiments. Indeed, the shape of any particular intensity curve may not be material after the normalization step.

[00033] Following the optional adjustment of the light source at step **414** in **Figure 4**, at step **416**, the processor of the control unit normalizes the color component intensity curves. As illustrated in **Figures 6A** and **6B**, the raw data from a calibration scan (**Figure 6A**) is multiplied by a scaling factor (for example, y_{max} of the RGB curves) to yield a set of normalized curves (**Figure 6B**) for a more effective comparison. The normalized RGB curves are substantially linear, which makes it easier to compare the relative intensities among the R, G, and B components. Furthermore, the normalized plot can more easily be thought of as the imaging subject's absorption plot (inverse of the reflected light intensity data acquired by the imaging unit). A more linear curve provided by the normalization step **416** facilitates easier detection of defects when compared to the product flow scans.

[00034] After normalization, at step **418**, system **100** optionally decides whether additional colors should be calibrated. If more colors are to be calibrated, method **400** cycles back to step **404**. If sufficient number of colors has been calibrated, the method **400** proceeds to the next step. At step **420**, system **100** moves the elevated platform **104** (either via the control unit or by the operator) out of the field of view of the line scan camera **300**. Because the calibration sequence (e.g., steps **404** through **420**) for each color is as short as a fraction of a second, calibration and recalibration can occur without having to interrupt the production flow. The processing time to validate or calibrate the colors can take up to about a minute, but the operation of the system is not effected during that time. The continuous production flow need not stop during calibration if the conveyor belt **102** is not moving at such a rapid pace so as to advance a so high volume of products during the calibration mode that it would affect quality control.

[00035] Upon exiting the calibration mode, system **100** proceeds to the defect detection mode. At step **422**, the imaging unit captures a line scan of the product on the conveyor belt **102** surface. As with the calibration scan, the acquired data is transmitted to the control unit through the control/data line **350**, and stored in the control unit memory. At step **424**, the control unit processor normalizes the color component intensities of the defect detection scans. The control unit processor then decides whether to continue scanning the products on the conveyor belt **102** surface at step **426**. If determined in the affirmative at step **426**, steps **422** and **424** are repeated. If determined in the negative, the processor accumulates the defect detection scans stored in the memory at step **428**. In some embodiments, system **100** continually repeats steps **422** through **426** while simultaneously transmitting the earlier acquired data to the control memory unit.

[00036] At step **430**, the processor determines whether a defect exists among the accumulated scan data. The defect determination step **430** is automated, in one embodiment, based on an algorithm comprising various factors, including the color, shape, or size of the defect. Not all potentially defective pixels are treated the same. Instead, each cluster or group of potentially defective pixels are assigned a quality index score. In some embodiments, the algorithm includes a set of threshold levels of quality index score for each type of defect. For example, a set of 300 orange pixels on a given potato chip may be deemed as defective as a set of 10 black pixels. Thus, a black defect may have a threshold level of 15 maximum pixels whereas an orange defect may have a threshold of 500 pixels. This is different than some prior art quality control methods where the presence of any single defect (or a pixel representing a defect) would be treated the same. The threshold values are chosen according to the needs of a particular application. The algorithm is stored in the control unit memory, and the processor calls upon the stored algorithm at step **432** to determine whether the defect size is above the relevant threshold. If so, system **100** sends a signal to the sorter to sort out the potentially defective product for further inspection. If not, method **400** proceeds to next steps. At step **434**, system **100** determines whether to continue scanning the product stream on the conveyor belt **102** surface. If determined in the affirmative, the method **400** cycles back to step **422** and the detection mode continues.

[00037] It should be noted that the data from the imaging unit can be influenced by subtle changes in settings or conditions. For example, even though the line scan camera **300** is focused on the calibration color tile **120**, if the surrounding area, such as the conveyor belt **102**, changes color, the line scan result changes. For example, the conveyor belt **102** after an extended use of transporting potato chips can become orange to brown color. Some of the light emitted from the light source **162** is absorbed by the conveyor belt **102**. Thus, when the calibration scan of a color tile **120** is taken against the backdrop of a clean conveyor belt **102** (as illustrated in **Figure 5B**) is compared to one that is taken against a used, brown conveyor belt **102** (as illustrated in **Figure 6A**), the blue intensity curve is noticeably lower in **Figure 6A**. Thus, as the conveyor belt **102** ages and changes color, system **100** may need recalibration. At step **436**, the processor determines whether recalibration is needed. If determined in the affirmative, the method **400** cycles back to step **404**. If determined in the negative, the method **400** proceeds to subsequent steps.

[00038] While method **400** has been above described in one embodiment, there are many possible embodiments and variations on the method of using system **100**. For example, as noted above, the adjustment of the light source **162** at step **414** can be an optional step. The recalibration step **436** can occur after the initial defect detection scan at step **422** or between any subsequent detection scans; the recalibration step **436** need not come after step **432**. Furthermore, the detection scan data need not be normalized at step **424** after each and every scan. The normalization **424** of the defect detection scans can occur after all of the detection data are accumulated at step **428**. One of ordinary skill in the art can appreciate that many of the steps in method **400** can be reordered, made optional, or occur substantially simultaneously without going beyond the scope of this disclosure.

[00039] Furthermore, the system **100** may also be varied. Specifically, the calibration reference unit need not comprise a color strip **120**. For example, as illustrated in **Figure 7**, the reference colors are arranged on a spinning roller **700** in one embodiment. The spinning roller **700** has a plurality of color segments **702**, **704**, **706**, **708**, **710**, which may be chosen according to the specific needs of an inspection process. In one embodiment, the roller **700** rests on a set of support posts **750** on either end of the roller **700**. In one embodiment, the control unit rotates the spinning roller **700** sufficient to place the next color segment in the field of view of the camera. The axis of rotation is through the center of the cylinder of the roller in one embodiment. But the color segments need not be a horizontal strip along the length of the spinning roller **700** as shown in **Figure 7**. In another embodiment (not shown), the color segments are arranged in a diagonal manner so that the spinning roller **700** may continuously rotate as the imaging unit continuously captures calibration scans of various colors.

[00040] In yet another embodiment, the color tiles **120** are affixed parallel to the direction of advancement of the conveyor belt **102** as illustrated in **Figure 8**. The parallel color strip **800** comprises a plurality of color segments **802**, **804**, **806**. **808**, **810** running parallel to the direction of the conveyor belt **102** in some embodiments. As the line scan camera travels along the path shown in dotted line, it captures both a product stream defect detection scan on the conveyor belt **102** as well as a calibration scan of the reference color strip **800**. Thus, each defect detection scan can be calibrated against the reference. In some embodiments, there is a barrier separating the conveyor belt **102** and the parallel color strip **800** within the system **100** enclosure to prevent any dust or waste accumulation on the parallel color strip **800**. The parallel color strip **800** need not run the entire length of the conveyor belt **102**, but can be long enough to cover the field of view of the imaging unit in some embodiments. A person having ordinary skill in the art would appreciate that in the embodiments where the parallel color strip **800** is used, many of the steps in method **400** can be either eliminated or occur simultaneously.

[00041] Although the present invention has been described with several embodiments, a myriad of changes, variations, alterations, transformations, and modifications may be suggested to one skilled in the art, and it is intended that the present invention encompass such changes, variations, alterations, transformations, and modifications as fall within the spirit and scope of the appended claims. Alternative embodiments that result from combining, integrating, or omitting features of the embodiments are also within the scope of the disclosure.

[00042] In order to assist the United States Patent and Trademark Office (USPTO) and any readers of any patent issued on this application in interpreting the claims appended hereto, Applicants wish to note that the Applicants: (a) do not intend any of the appended claims to invoke paragraph six (6) of 35 U.S.C. section 112 as it exists on the date of the filing hereof unless the words “means for” or “step for” are specifically used in the particular claims; and (b) do not intend, by any statement in the specification, to limit this invention in any way that is not otherwise reflected in the appended claims.

CLAIMS

What is claimed is:

1. A method of calibrating a dynamic digital imaging system for detecting defects in a production stream on a conveyor having a plurality of articles of products, wherein the method comprises:
   a) placing a calibration color tile on a platform elevated above the conveyor in a field of view of imaging unit;
   b) obtaining light absorption data of the calibration color using the imaging unit;
   c) calculating a component color intensity of the light absorption data of the calibration color using a processor;
   d) normalizing the component color intensities of the calibration color;
   e) removing the platform out of the field of view of the imaging unit; and
   f) obtaining light absorption data of the products using the imaging unit;

2. The method of claim 1 further comprising:
   g) calculating one or more component color intensity of the light absorption data of the products using the processor;
   h) normalizing the component color intensities of the products; and
   i) calculating a quality index score of the products based on the component color intensities of the calibration color and the products.

3. The method of claim 2 further comprising:

   j) recalling a defect threshold data stored in a memory; and

   k) comparing the quality index score with the defect threshold data.

4. The method of claim 1, wherein the platform is removed out of the field of view of the imaging unit by moving in the direction parallel to the flow of the conveyor.

5. The method of claim 1, wherein the platform is removed out of the field of view of the imaging unit by moving in the direction perpendicular to the flow of the conveyor.

6. The method of claim 1 further comprising adjusting an output intensity of an illumination source.

7. The method of claim 6, wherein the output intensity of the illumination source is adjusted based on light absorption data of the calibration color.

8. The method of claim 6, wherein the output intensity of the illumination source is adjusted based on light absorption data of the products.

9. The method of claim 1 further comprising adjusting a direction of an illumination source using a reflector.

10. The method of claim 9 wherein the direction of the illumination source is adjusted based on light absorption data of the calibration color.

11. A system for calibrating a dynamic digital imaging system for detecting defects in production stream comprising:

a conveyor unit having a first frame extending along at least a portion of a width of a conveyor unit;

a platform elevated above the conveyor unit a first support movably coupled to a track within the first frame; and

a slot within the platform for receiving a reference color tile.

12. The system of claim 11 wherein the reference color tile comprises a plurality of reference color segments.

13. The system of claim 11 further comprising a second frame positioned directly across the width of the conveyor unit the first frame, wherein the platform is further supported by a second support removably couple to a track within the second frame.

14. The system of claim 11 wherein the platform is elevated at least about 7 centimeters from an upper surface of the conveyor unit.

15. The system of claim 11 further comprising an imaging unit comprising a camera having a field of view, a camera window, and a control/data line.

16. The system of claim 15 wherein the camera is a linear array of light sensors.

17. The system of claim 11 further comprising a lighting unit comprising a light source and a reflector.

18. The system of claim 11 wherein the support is a beam operable to move within the track.

19. The system of claim 11 further comprising a control unit comprising a processor, a memory, and a display device wherein further an imaging unit is in communication with the control unit through the control/data line.

20. The system of claim 11 wherein the color tile comprises a roller operable to rotate about its longitudinal axis.

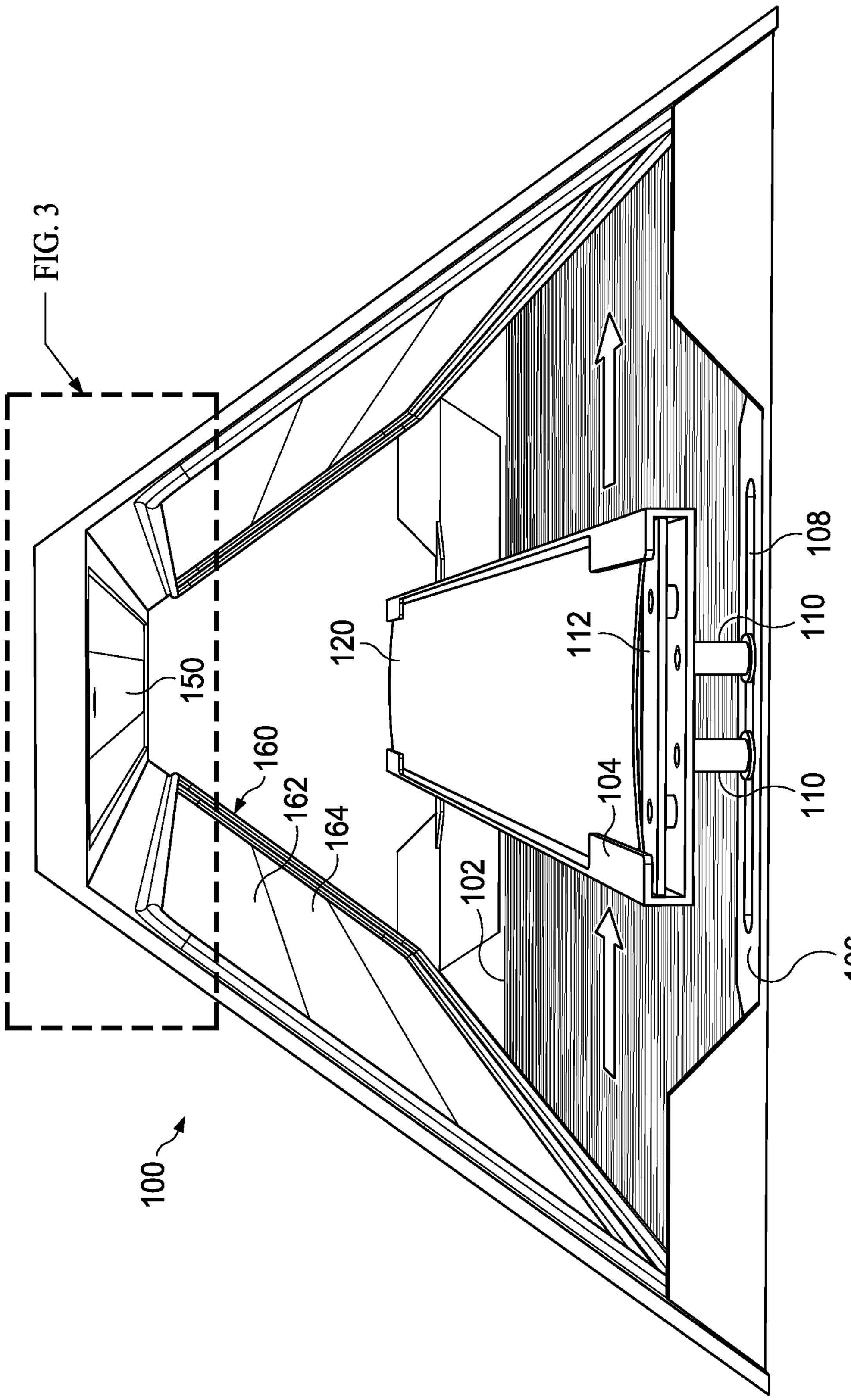


FIG. 1

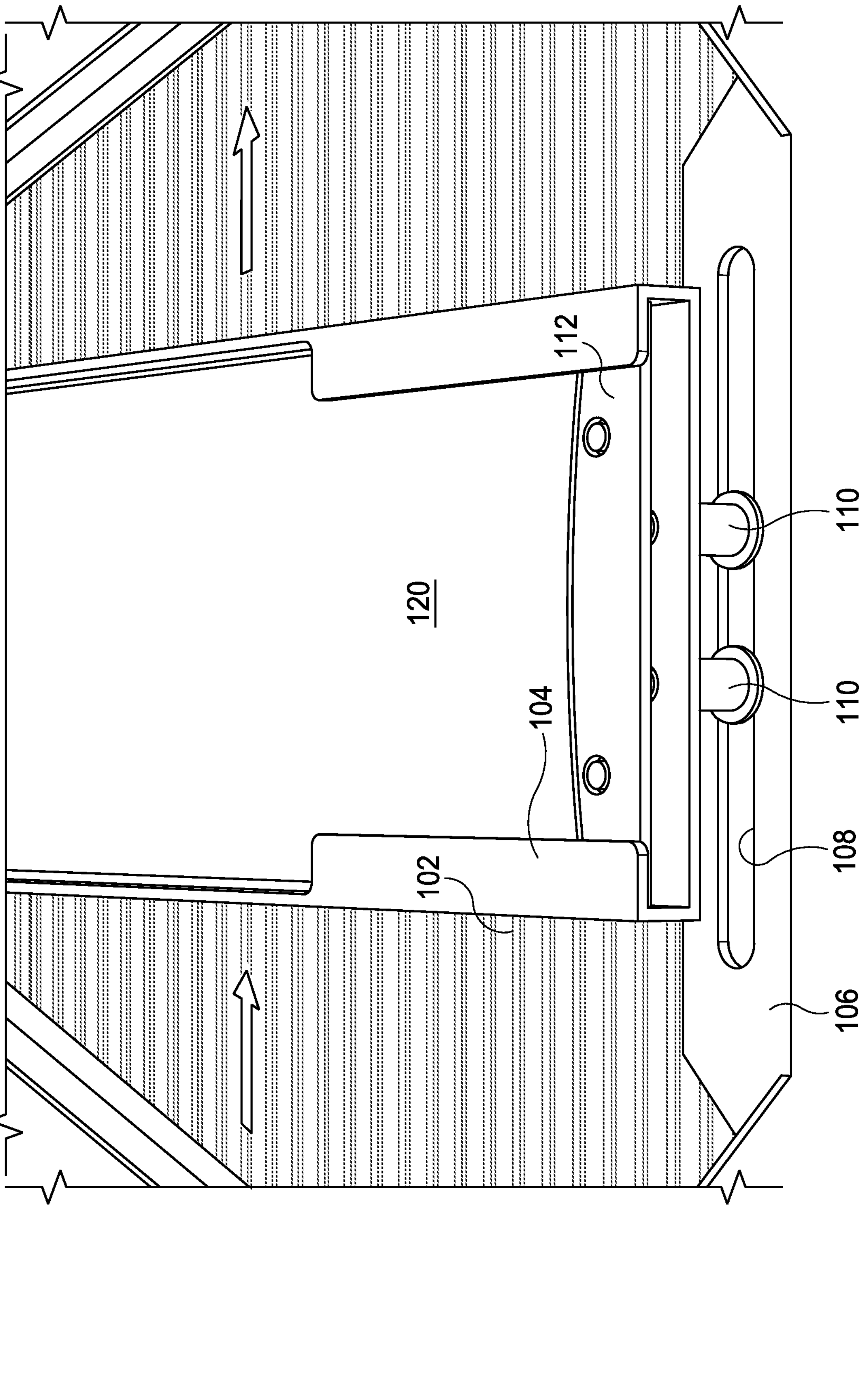
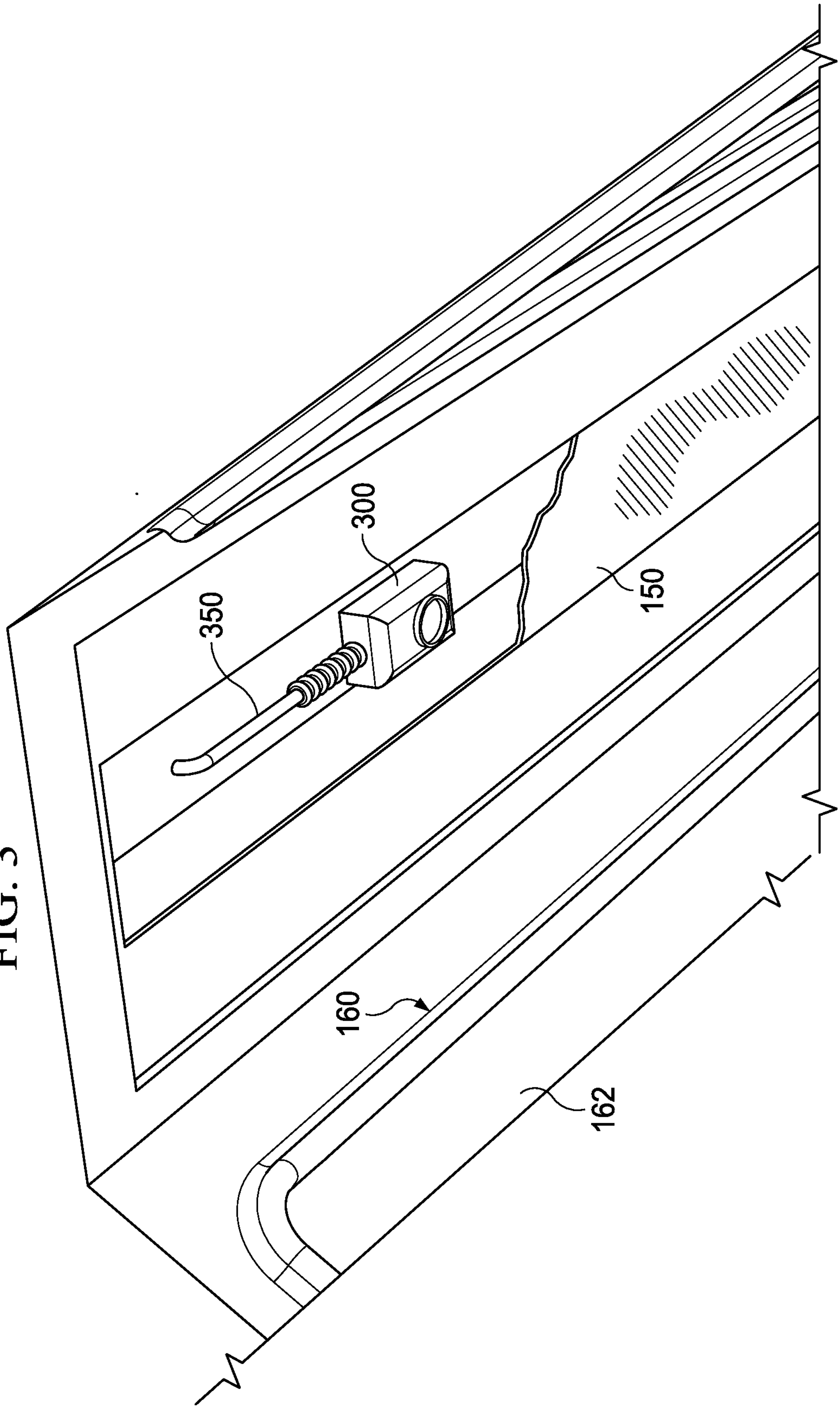


FIG. 2

FIG. 3



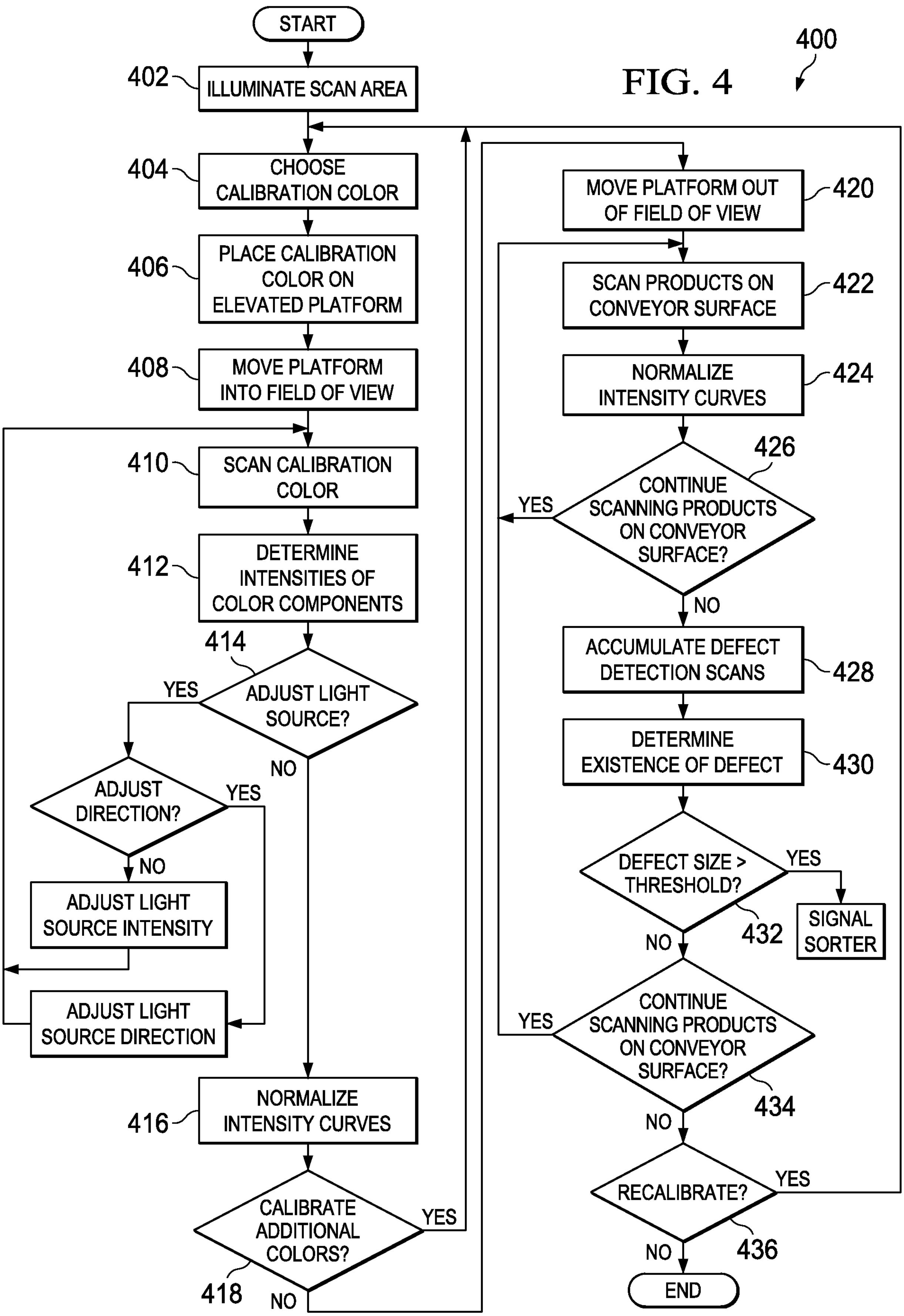
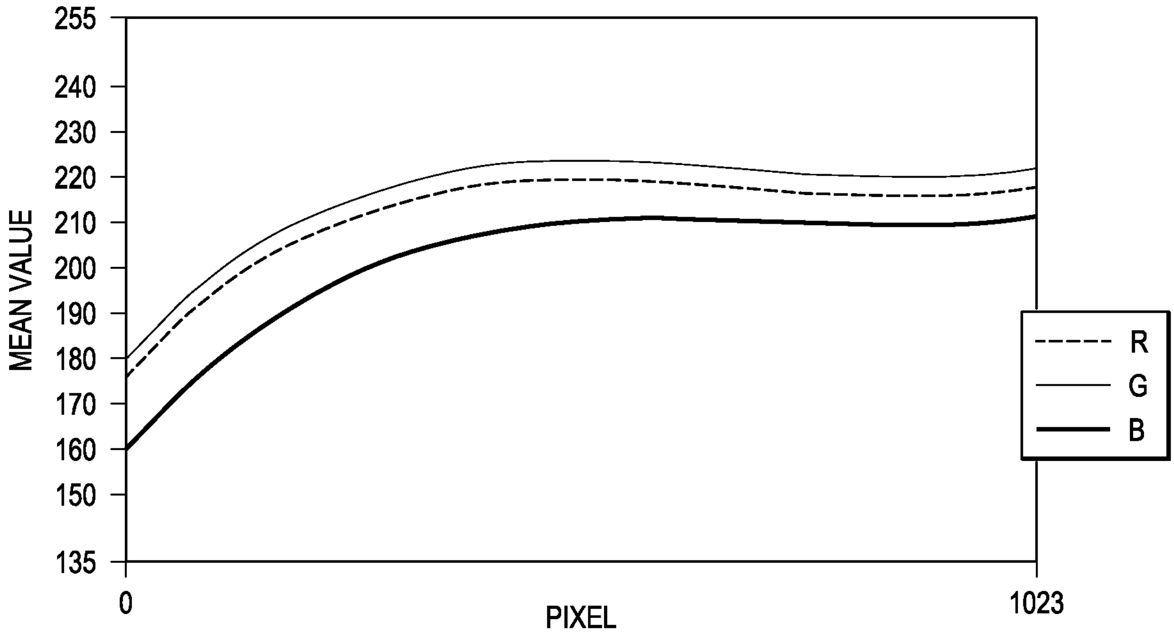

400
START
402 ILLUMINATE SCAN AREA
404 CHOOSE CALIBRATION COLOR
406 PLACE CALIBRATION COLOR ON ELEVATED PLATFORM
408 MOVE PLATFORM INTO FIELD OF VIEW
410 SCAN CALIBRATION COLOR
412 DETERMINE INTENSITIES OF COLOR COMPONENTS
414 ADJUST LIGHT SOURCE?
YES
NO
ADJUST DIRECTION?
YES
NO
ADJUST LIGHT SOURCE INTENSITY
ADJUST LIGHT SOURCE DIRECTION
416 NORMALIZE INTENSITY CURVES
418 CALIBRATE ADDITIONAL COLORS?
YES
NO
420 MOVE PLATFORM OUT OF FIELD OF VIEW
422 SCAN PRODUCTS ON CONVEYOR SURFACE
424 NORMALIZE INTENSITY CURVES
426 CONTINUE SCANNING PRODUCTS ON CONVEYOR SURFACE?
YES
NO
428 ACCUMULATE DEFECT DETECTION SCANS
430 DETERMINE EXISTENCE OF DEFECT
432 DEFECT SIZE > THRESHOLD?
YES
NO
SIGNAL SORTER
434 CONTINUE SCANNING PRODUCTS ON CONVEYOR SURFACE?
YES
NO
436 RECALIBRATE?
YES
NO
END

FIG. 4

FIG. 5A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230
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190
180
170
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150
135
MEAN VALUE
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PIXEL
1023
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G
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FIG. 5B

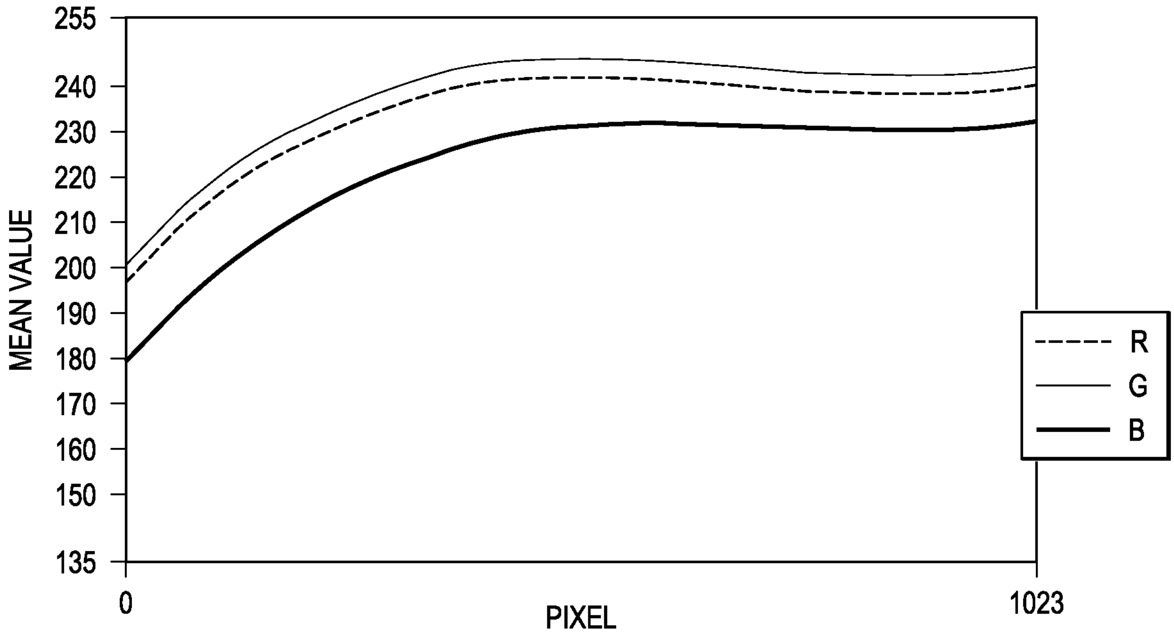
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FIG. 6A

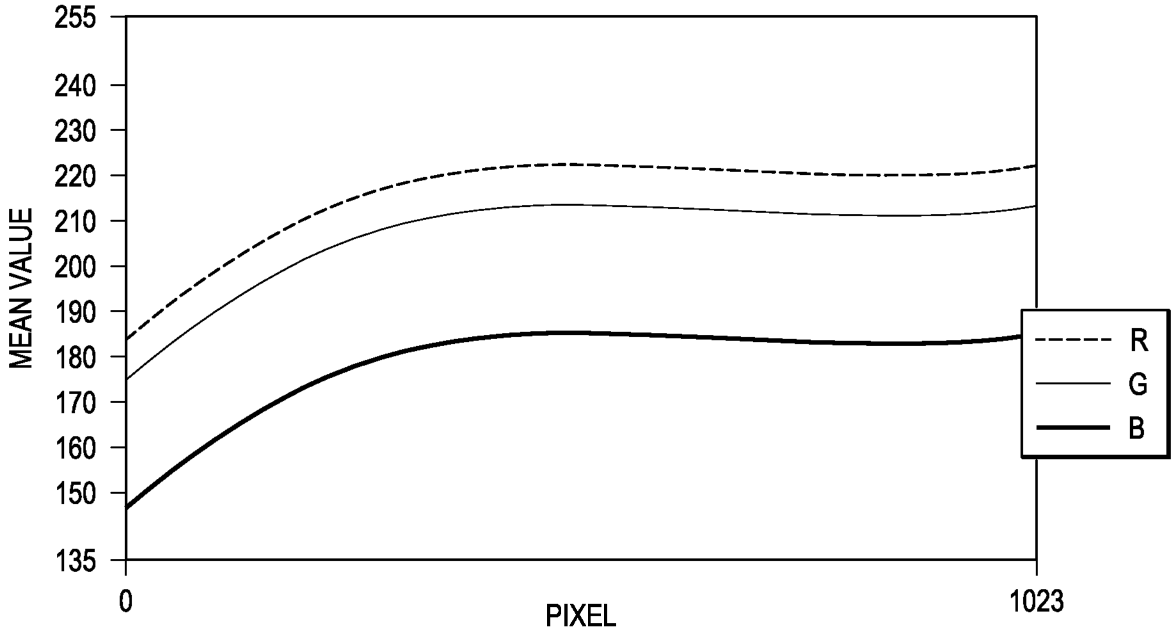
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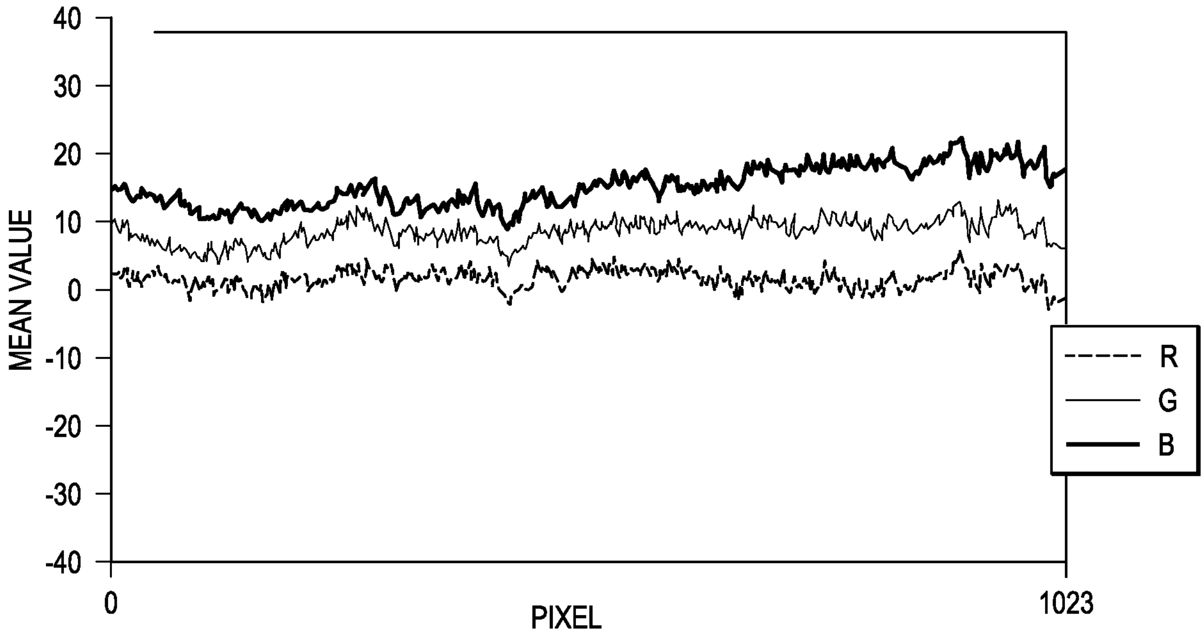
FIG. 6B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-40
MEAN VALUE
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PIXEL
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G
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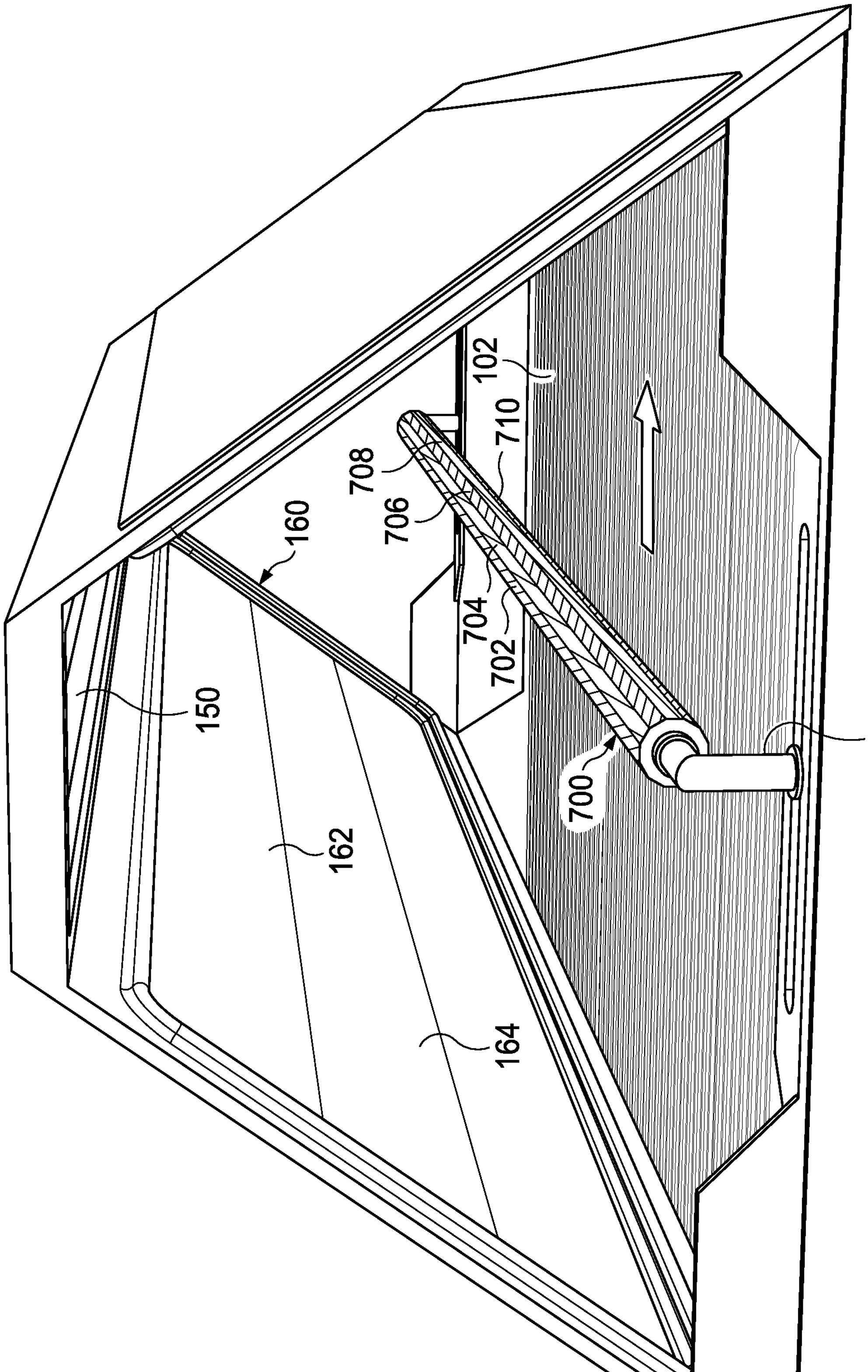
FIG. 7



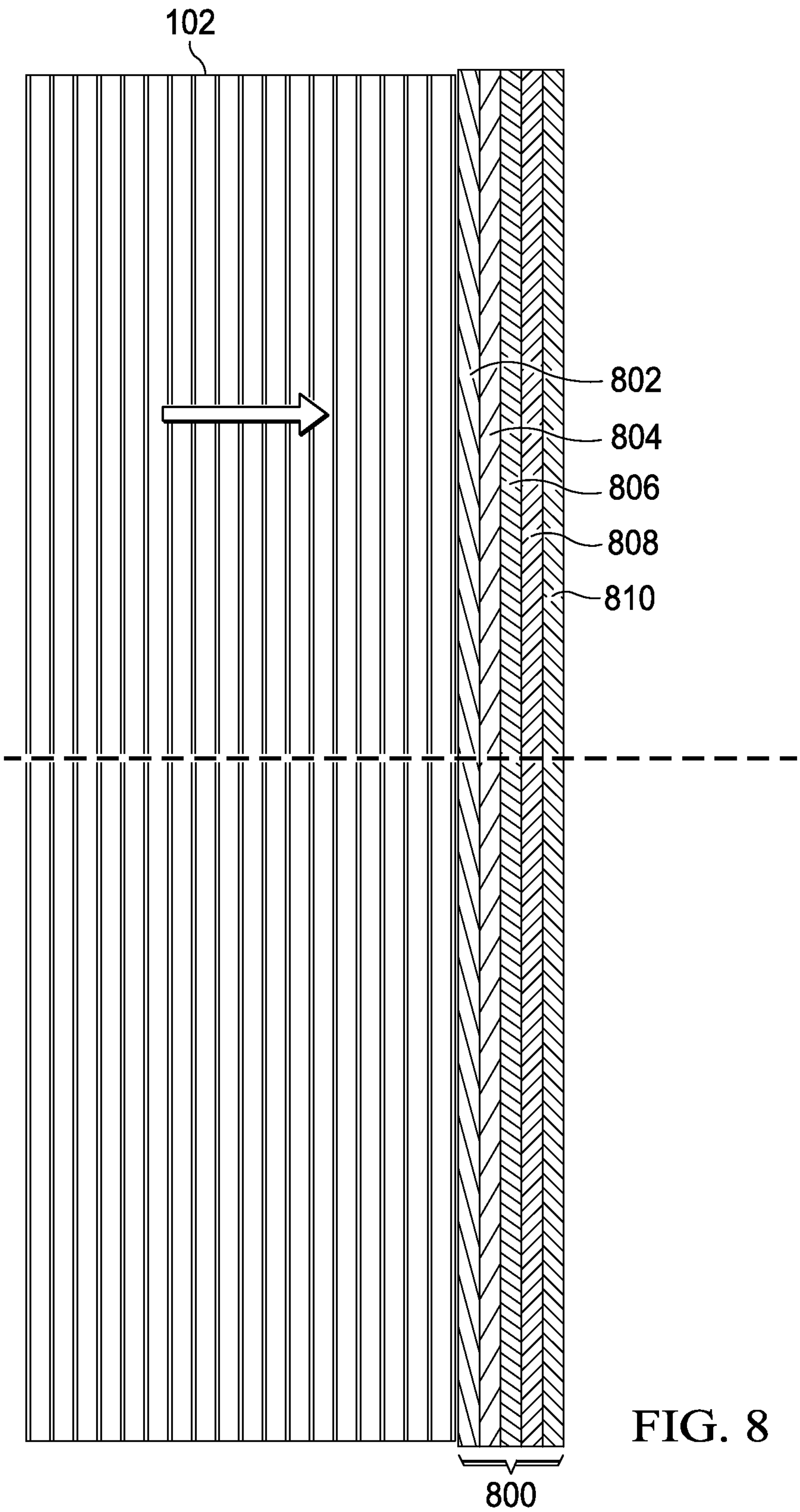


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/071490

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01R 33/58 (2014.01)
USPC - 356/228
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)
IPC(8) - G01C 25/00, G01D 18/00, G01N 3/62, G01N 21/93, G01P 21/00, G01R 33/58, G05B 19/401 (2014.01)
USPC -193/35R, 193/342, 198/570, 198/584, 198/681, 198/466.1, 356/228, 356/237.1, 356/239.2, 356/243.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - G01R 33/58, G01R 31/2806, G05B 19/401 (2013.01)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y ----- A	US 2007/0153277 A1 (SHAKESPEARE et al) 05 July 2007 (05.07.2007) entire document	1-10 ----- 11-20
Y ----- A	US 5,887,702 A (MOTT) 30 March 1999 (30.03.1999) entire document	1-10 ----- 11-20
Y ----- A	US 3,840,931 A (BIVENS) 15 October 1974 (15.10.1974) entire document	4, 5 ----- 11-20
Y	US 2009/0056872 A1 (GROVE) 05 March 2009 (05.03.2009) entire document	1-20
Y	US 2001/0048765 A1 (YI et al) 06 December 2001 (06.12.2001) entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"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
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 March 2014	18 APR 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774