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(54) Title: PHOTOGRAMMETRY MEASUREMENT SYSTEM



ABSTRACT

5 A method and apparatus for making measurements. Images of an
object are generated. A plurality of coordinates for a plurality of points on a
surface of the object is identified from the images using a number of reference
points in the images. A first portion of the plurality of points on the object is
visible on the object in the images. A second portion of the plurality of points
on the object is visible on a number of mirror units in the images.

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PHOTOGRAMMETRY MEASUREMENT SYSTEM

BACKGROUND

5 The present disclosure relates generally to measurements and, in particular, to measuring objects. Still more particularly, the present disclosure relates to a method and apparatus for identifying coordinates of objects in images.

10 Photogrammetry is a three-dimensional coordinate measurement technique. This technique uses photographs as a medium to make measurements. With photogrammetry, triangulation is used to identify coordinates of objects. Images of an object are generated from at least two different locations to points on an object. Each point on the object is a location on the object. The lines from these locations to the points on the object may also be referred to as lines of sight or rays. These lines of sight
15 may be processed mathematically to identify three-dimensional coordinates for the points on the object.

With photogrammetry, images are generated using camera systems. Typically, the camera systems have two or more cameras at different locations. The cameras are located at the locations from which lines of sight
20 are identified to point on an object. With the images generated by the cameras, three-dimensional information, such as a three-dimensional location of points, is identified.

The mathematic processing in photogrammetry involves using triangulation to identify three-dimensional coordinates for points in the images.
25 The different cameras provide lines of sight to the different points that may converge in space. With images of an object containing the points, a line of sight may be identified from each camera to the points on the object. If the location of the camera and the aiming direction is known, the lines of sight may be used to identify three-dimensional coordinates for each point.

30 In generating images for identifying coordinates for points on an object, the camera system is positioned such that any given point on the object can be seen by both of the cameras in the camera system at the point in time the image of the object is generated. Further, additional images may be generated for use in increasing accuracy of measurements.

When points on an object are hidden from the view of the camera system, measurements of these points cannot be made. In some cases, not all of the points of interest for measurements on an object can be seen from the camera system from any one position.

5 One solution involves moving the camera system to another location such that the cameras are positioned to generate images of the points that were hidden from view in the first location. Although this type of process provides coordinates for the desired points, additional time and calculations are needed when the camera system is moved from one location to another
10 location.

SUMMARY

15 In accordance with one aspect of the invention there is provided an apparatus including a number of mirror units configured to be positioned relative to an object. The apparatus also includes a number of cameras configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images. A first portion of the plurality of points on the object is visible on the object in the images and
20 a second portion of the plurality of points on the object is visible on the number of mirror units in the images. generating a substantially spatially correct point cloud for the object using the plurality of coordinates for the plurality of points, wherein points in the substantially spatially correct point cloud have substantially same locations as corresponding points in the plurality of points
25 on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the plurality of points on the object. The apparatus further includes a measurement module configured to identify a plurality of coordinates for the plurality of points using the images, a plurality of positions for the number of cameras relative to the object, a number
30 of reference points in the images, and a number of positions for the number of

mirror units. The plurality of coordinates for the plurality of points on the object are used to form a substantially spatially correct point cloud for the object.

5 The apparatus may include a laser device configured to generate a plurality of markers on the plurality of points, and the plurality of markers on the plurality of points may be visible in the images.

10 A mirror unit in the number of mirror units may include a mirror having a first surface, and a frame surrounding the mirror and having a second surface, and the frame may be configured to hold the mirror such that the first surface is substantially coplanar with the second surface and at least a portion of the number of reference points may be on the frame in the images.

15 In identifying the plurality of coordinates for the plurality of points using the images, the measurement module may be configured to identify an intersection of lines of sight for the number of cameras, where each of the lines of sight is between a camera in the number of cameras and a reflection of a point in the second portion of the plurality of points on a mirror unit in the number of mirror units, rotate the point at which the intersection occurs about 180 degrees relative to a plane for the mirror unit to form a new point, and identify a coordinate for the new point.

20 The measurement module may be configured to apply a policy to the plurality of coordinates for the plurality of points.

25 Points in the substantially spatially correct point cloud may have substantially same locations as corresponding points in the plurality of points on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the plurality of points on the object.

The measurement module may be configured to generate a model of the object using the substantially spatially correct point cloud.

The measurement module may be configured to compare the model of the object with another model of the object and identify a number of

differences between the model of the object and the another model of the object.

A line of sight for a camera in the number of cameras between the camera and a point in the second portion of the plurality of points may be absent.

The first portion of the plurality of points may be a number of visible points and the second portion of the plurality of points may be a number of hidden points in which the number of hidden points are hidden from a direct view of the number of cameras.

In accordance with another aspect of the invention there is provided a method for making measurements. The method involves generating images of an object, and identifying a plurality of coordinates for a plurality of points on a surface of the object from the images using a number of reference points in the images. A first portion of the plurality of points on the object is visible on the object in the images, and a second portion of the plurality of points on the object is visible on a number of mirror units in the images. The method also involves generating a substantially spatially correct point cloud for the object using the plurality of coordinates for the plurality of points, points in the substantially spatially correct point cloud having substantially same locations as corresponding points in the plurality of points on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the plurality of points on the object.

The method may involve generating a plurality of markers on the plurality of points on the surface of the object using a laser device.

The generating step may be performed using a number of cameras and the step of identifying the plurality of coordinates for the plurality of points on the surface of the object from the images may involve identifying an intersection of lines of sight for the number of cameras, where each of the lines of sight is between a camera in the number of cameras and a reflection of a point in the second portion of the plurality of points on a mirror unit in the

number of mirror units, rotating the point at which the intersection occurs about 180 degrees relative to a plane for the mirror unit to form a new point, and identifying a coordinate for the new point.

5 The method may involve generating a model for the object using the substantially spatially correct point cloud.

The method may involve comparing the model of the object with another model of the object, and identifying a number of differences between the model of the object and the another model of the object.

10 A mirror unit in the number of mirror units may include a mirror having a first surface and a frame surrounding the mirror and having a second surface, where the frame is configured to hold the mirror such that the first surface is substantially coplanar with the second surface and where at least a portion of the number of reference points are on the frame in the images.

15 The generating step may be performed using a number of cameras and a line of sight for a camera in the number of cameras between the camera and a point in the second portion of the plurality of points may be absent.

20 The first portion of the plurality of points may be a number of visible points and the second portion of the plurality of points is a number of hidden points in which the number of hidden points is hidden from a direct view of a number of cameras configured to generate the images of the object.

25 In accordance with another aspect of the invention there is provided an apparatus including a number of mirror units configured to be positioned relative to an object, and a number of cameras configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images. The apparatus also includes a measurement module configured to identify a plurality of coordinates for the plurality of points using a number of reference points in the images, a first portion of the plurality of points on the object being visible on the object in the images, and a second portion of the plurality of points on the object being visible on the number of mirror units in the images. The apparatus is further configured to generate a

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point cloud for the object using the plurality of coordinates for the plurality of points, and points in the point cloud have substantially the same locations as corresponding points in the plurality of points on the object when the points in the point cloud are aligned with the corresponding points in the plurality of points on the object.

The features and functions may be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the embodiments are set forth in the appended claims. The embodiments, however, as well as a preferred mode of use will best be understood by reference to the following detailed description of an embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an illustration of an aircraft manufacturing and service method in accordance with an embodiment;

Figure 2 is an illustration of an aircraft in which an embodiment may be implemented;

Figure 3 is an illustration of a measurement environment in accordance with an embodiment;

Figure 4 is an illustration of a measurement environment in accordance with an advantageous embodiment;

Figure 5 is an illustration of a measurement of hidden points in accordance with an embodiment;

Figure 6 is an illustration of a mirror unit in accordance with an embodiment;

Figure 7 is an illustration of a cross-sectional view of a mirror unit in accordance with an embodiment;

5 Figure 8 is an illustration of a point cloud for a measurement environment in accordance with an embodiment;

Figure 9 is an illustration of a flowchart of a process for making measurements for an object in accordance with an embodiment;

10 Figure 10 is an illustration of a flowchart of a process for identifying a coordinate for a hidden point on an object in accordance with an embodiment; and

Figure 11 is an illustration of a data processing system in accordance with an embodiment.

15 DETAILED DESCRIPTION

Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of an aircraft manufacturing and service method 100 as shown in Figure 1 and an aircraft 200 as shown in Figure 2. Turning first to Figure 1, an illustration of an aircraft manufacturing and service method is depicted in accordance with an advantageous embodiment. During pre-production, the aircraft manufacturing and service method 100 may include a specification and design 102 of the aircraft 200 in Figure 2 and a material procurement 104.

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During production, a component and subassembly manufacturing **106** and a system integration **108** of the aircraft **200** in Figure **2** takes place. Thereafter, the aircraft **200** in Figure **2** may go through a certification and delivery **110** in order to be placed in service **112**. While in service **112** by a customer, the aircraft **200** in Figure **2** is scheduled for routine maintenance and service **114**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of the aircraft manufacturing and service method **100** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

With reference now to Figure **2**, an illustration of an aircraft is depicted in which an advantageous embodiment may be implemented. In this example, the aircraft **200** is produced by the aircraft manufacturing and service method **100** in Figure **1** and may include an airframe **202** with a plurality of systems **204** and an interior **206**. Examples of the systems **204** include one or more of a propulsion system **208**, an electrical system **210**, a hydraulic system **212**, and an environmental system **214**. Any number of other systems may be included. Although an aerospace example is shown, different advantageous embodiments may be applied to other industries, such as the automotive industry.

Apparatuses and methods embodied herein may be employed during at least one of the stages of the aircraft manufacturing and service method **100** in Figure **1**. As used herein, the phrase “at least one of”, when used with a list of items, means that different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, and item C” may include, for example, without limitation, item A, or item A and item B. This example may also include item A, item B, and item C, or item B and item C.

In one illustrative example, components or subassemblies produced in the component and subassembly manufacturing **106** in Figure **1** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **200** is in service **112** in Figure **1**.

5 These components may be measured using one or more of the different advantageous embodiments. As yet another example, a number of apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages, such as the component and subassembly manufacturing **106** and the system integration **108** in Figure **1**.

10 A number, when referring to items, means one or more items. For example, a number of apparatus embodiments may be one or more apparatus embodiments. A number of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **200** is in service **112** and/or during the maintenance and service **114** in Figure **1**. The
15 use of a number of the different advantageous embodiments may substantially expedite the assembly of and/or reduce the cost of the aircraft **200**.

For example, measurements of points on objects may be made during one or more of these stages using the different advantageous embodiments. The objects may be the aircraft **200** and/or any components of the aircraft
20 **200**. The advantageous embodiments may be used to identify the location of points on objects in three dimensions. With the identification of these points using the different advantageous embodiments, measurements may be made of the points for the object. For example, point clouds may be generated for an object. The point clouds may then be used to determine whether different
25 points on the object meet desired manufacturing and/or testing parameters, tolerances, or other desired values.

The different advantageous embodiments recognize and take into account that one solution may be to move the part and/or the camera system to different positions to generate images for all points on the object. However,
30 this type of procedure may take more time and/or effort than is desirable. As yet another solution, a number of measurement probes and/or the camera system may be moved around the part to generate measurements for the points on the object. Using this type of measurement system may also take more time, effort, and more calculations than is desirable.

The different advantageous embodiments recognize and take into account that one solution that does not require moving the camera systems may be to use mirrors when generating images of the objects. For example, the mirror may be placed in a position such that the camera is able to generate an image including the points hidden from view. In other words, the different advantageous embodiments recognize and take into account that the mirror may be positioned such that the image generated from the mirror includes points on the object that does not have a direct line of sight from the camera.

Thus, the advantageous embodiments provide a method and apparatus for making measurements. In making measurements, coordinates are identified for points on an object. With the identification of coordinates for these points on the object, measurements may be made for the object. These measurements may be used to determine whether the object meets a policy or some rules or criteria for the object.

In one advantageous embodiment, an apparatus comprises a number of mirror units, a number of cameras, and a measurement module. The number of mirror units is configured to be positioned relative to the object. The number of cameras is configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images. A first portion of the plurality of points may be visible on the object in the image, while a second portion of the plurality of points in the images is hidden. The second portion of the plurality of points is visible in the number of mirror units in the images. The measurement module is configured to identify a location of the plurality of points using the images, the plurality of positions for the number of cameras, and a number of positions for the number of mirror units.

With reference now to Figure 3, an illustration of a measurement environment is depicted in accordance with an advantageous embodiment. In this illustrative example, a measurement environment **300** comprises a measurement system **302**. The measurement system **302** is used to make measurements of an object **304**. In these examples, the measurement system **302** takes the form of a photogrammetry system **306**.

As depicted, the photogrammetry system **306** comprises a camera system **308**, a scanner **310**, and a mirror unit **312**. The camera system **308** includes a first camera **314** and a second camera **316**. The first camera **314**, the second camera **316**, and the scanner **310** are associated with a frame **318**.

A first component, such as the first camera **314**, may be considered to be associated with a second component, such as the frame **318**, by being secured to the second component, bonded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component may also be connected to the second component using a number of other components. The first component may also be considered to be associated with the second component by being formed as part of and/or an extension of the second component.

In these illustrative examples, the photogrammetry system **306** is used to measure points **320** on the object **304**. The scanner **310** may project dots **319** onto the object **304** in the locations of the points **320** on the object **304** for which measurements are to be made. The dots **319** are dots formed using coherent light from the scanner **310**. The dots **319** are just one illustrative example of markers that may be used to identify the locations of the points **320** in images generated by the photogrammetry system **306**.

In other words, a dot is projected onto the object **304** at each location of a point on the object **304** for which measurements are to be made. In this manner, the dots **319** make the points **320** on the object **304** visible to the camera system **308**.

In these illustrative examples, the scanner **310** may take the form of a laser scanning system configured to project the dots **319** onto the object **304**.

5 In this illustrative example, the object **304** has a visible portion **323** of the points **320** on the object **304** and a hidden portion **322** of the points **320** on the object **304** relative to a current position **321** of the camera system **308**. For example, the visible portion **323** of the points **320** on the object **304** is visible to the camera system **308** when the camera system **308** is in the current position **321**. In other words, the camera system **308** has a direct line of sight to each point in the visible portion **323** of the points **320** on the object **304**. In this manner, both the first camera **314** and the second camera **316** can generate images that include the visible portion **323** of the points **320** on the object **304**.
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Further, the hidden portion **322** of the points **320** on the object **304** is hidden from the camera system **308** when the camera system **308** is in the current position **321**. In other words, the camera system **308** does not have a direct line of sight to any point in the hidden portion **322** of the points **320** on the object **304**. In this illustrative example, the first camera **314** and the second camera **316** are unable to generate images that show the dots **319** on the hidden portion **322** of the points **320** on the object **304** without using, for example, the mirror unit **312**.
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In these illustrative examples, the mirror unit **312** is positioned such that an image includes the mirror unit **312**. The image with the mirror unit **312** includes a reflection of the hidden portion **322** of the points **320** on the object **304** in the images generated by the first camera **314** and the second camera **316**. In the different illustrative examples, the mirror unit **312** may be any object capable of providing a reflection. In other words, the mirror unit **312** may be any object capable of providing a reflection of the object **304** that may be captured in the images generated by the first camera **314** and the second camera **316**.
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In this manner, the frame **318** with the camera system **308** and the scanner **310** does not need to be moved or repositioned to generate images for the hidden portion **322** of the points **320** on the object **304**.
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In these illustrative examples, the images generated by the camera system **308** are sent to a computer **324**. The computer **324** may then analyze the images and identify coordinates for the points **320** on the object **304**. Further, the computer **324** may analyze the coordinates for the different points on the object **304** to make measurements for the object **304**.

With reference to Figure 4, an illustration of a measurement environment is depicted in accordance with an advantageous embodiment. The measurement environment **300** in Figure 3 is an example of one implementation for a measurement environment **400** in Figure 4. In this depicted example, the measurement environment **400** comprises a measurement system **402**. The measurement system **402** makes measurements **404** of an object **406**. In particular, the measurement system **402** makes the measurements **404** for a plurality of points **408** on the object **406**.

In these examples, the plurality of points **408** is located on a surface **410** of the object **406**. In other words, each point in the plurality of points **408** is at a particular location on the surface **410** of the object **406**.

In particular, the measurement system **402** takes the form of a photogrammetry system **412**. In this example, the photogrammetry system **412** comprises a camera system **414**, a mirror system **416**, and a measurement module **418**. The camera system **414** is comprised of a number of cameras **420**. The measurement module **418** takes the form of hardware **424**, software **426**, or a combination of the two. The mirror system **416** is comprised of a number of mirror units **422**.

In these illustrative examples, the number of cameras **420** generates images **430** of the object **406**. The images **430** are sent to the measurement module **418**. The measurement module **418** in turn generates the measurements **404** for the plurality of points **408** on the surface **410** of the object **406**.

The plurality of points **408** may be identified in a number of different ways. For example, the plurality of points **408** may be identified using a plurality of markers **432**. The plurality of markers **432** are visible markers positioned on the plurality of points **408**. In this manner, the plurality of markers **432** make the plurality of points **408** visible in the images **430**.

In these illustrative examples, the plurality of markers **432** may be generated on the plurality of points **408** using a laser device **433**. The laser device **433** may also be referred to as a laser projection system. In particular, the laser device **433** may be configured to project the plurality of markers **432** on the plurality of points **408** on the surface **410** of the object **406**. For example, the laser device **433** may be used to project the plurality of markers **432** in the form of dots on the plurality of points **408** on the surface **410** of the object **406**.

In other illustrative examples, the plurality of markers **432** may be physical markers, such as paint, stickers, objects, or other suitable types of items that may be placed on the surface **410** of the object **406**. In this manner, the plurality of points **408** on the surface **410** of the object **406** may be seen in the images **430** generated by the camera system **414**.

As one illustrative example, a marker **435** in the plurality of markers **432** may be projected onto a point **434** in the plurality of points **408** on the surface **410** of the object **406**. The marker **435** on the point **434** is present in the images **430** generated by the camera system **414**.

In these illustrative examples, the number of cameras **420** may have a plurality of positions **440** relative to the object **406**. For example, when the number of cameras **420** is one camera, the camera is used to generate an image in the images **430** of the object **406** in one position in the plurality of positions **440**. Then, the camera may be moved from the position in the plurality of positions **440** to another position in the plurality of positions **440** to generate another image in the images **440** of the object **406**. In this manner, the camera may be moved to the different positions in the plurality of positions **440** to generate the images **430**.

As another example, the camera may be maintained in one position in the plurality of positions **440** while the object **406** is moved into different positions at which the images **430** are generated. For example, the object **406** may be rotated into a different position and/or moved from one position to another position. In this manner, when the number of cameras **420** is one camera, the camera has different positions relative to the object **406** when the camera and/or the object **406** are moved.

Additionally, when the number of cameras **420** is two or more cameras, the two or more cameras may be placed in the plurality of positions **440** to generate the images **430** from the plurality of positions **440**. In this manner, movement of the two or more cameras **420** to different positions may be unnecessary.

The number of cameras **420** has a plurality of lines of sight **436** from the plurality of positions **440** to the point **434** on the object **406** in these examples. In other words, in these illustrative examples, each of the plurality of lines of sight **436** is a line extending from one of the plurality of positions **440** for the number of cameras **420** to the point **434**.

In these illustrative examples, a first portion **442** of the plurality of points **408** on the object **406** may be visible on the object **406** in the images **430**. The first portion **442** of the plurality of points **408** is a number of visible points **444** on the object **406**. The number of visible points **444** includes the points on the object **406** that are in a direct view of the number of cameras **420**. In other words, each of the number of cameras **420** has a direct line of sight to the number of visible points **444** on the object **406** when in one of the plurality of positions **440**. In this manner, the number of visible points **444** is visible on the object **406** in the images **430**.

The second portion **446** of the plurality of points **408** on the object **406** is visible on the number of mirror units **422** in the images **430**. The second portion **446** of the plurality of points **408** is a number of hidden points **448** on the object **406**. The number of hidden points **448** on the object **406** includes the points on the object **406** that are not in a direct view of the number of cameras **420**. In other words, a line of sight from any camera in the number of cameras **420** from a position in the plurality of positions **440** to any hidden point in the number of hidden points **448** is absent or not present.

In this manner, the number of hidden points **448** on the object **406** are not visible on the object **406** in the images **430**. However, the number of hidden points **448** on the object **406** is visible on the number of mirror units **422** in the images **430**. In particular, a number of reflections **454** of the number of hidden points **448** is visible on the number of mirror units **422** and in the images **430**.

In other words, plurality of lines of sight **436** are only present between the plurality of positions **440** of the number of cameras **420** to the number of visible points **444**. The plurality of lines of sight **436** is absent or not present between the plurality of positions **440** of the number of cameras **420** to the number of hidden points **448**.

Instead, the number of mirror units **422** may have a number of positions **452** such that the number of hidden points **448** can be seen in the images **430**. For example, the images **430** generated by the number of cameras **420** include the number of mirror units **422**. In the images **430**, the number of mirror units **422** shows the number of reflections **454**. The number of reflections **454**, in these illustrative examples, shows the number of hidden points **448**. As a result, the number of hidden points **448** can be seen directly in the images **430**.

In these illustrative examples, the measurement module **418** may take the form of a computer system **456**. The measurement module **418** is configured to identify a plurality of coordinates **458** for the plurality of points **408** on the object **406**. The measurement module **418** identifies a first number of coordinates **460** for the number of visible points **444** and a second number of coordinates **462** for the number of hidden points **448**.

Depending on the implementation, the identification of the plurality of coordinates **458** may be performed without needing to move the camera system **414** or any other components in the photogrammetry system **412**.

However, in some cases, a third portion **463** of the plurality of points **408** may not be visible in the images **430** on the object **406** or on the number of mirror units **422**. In these cases, the object **406** may be moved and/or rotated to change the plurality of positions **444** of the number of cameras **420** relative to the object **406**. The object **406** may be moved and/or rotated such that the third portion **463** of the plurality of points **408** may be visible in the images **430**, generated by the number of cameras **420**, on at least one of the object **406** and the number of mirror units **422**.

In this manner, additional coordinates may be identified in the plurality of coordinates **458** for the third portion **463** of the plurality of points **408** on the object **406**. As a result, the plurality of coordinates **458** for substantially all portions of the surface **410** of the object **406** may be identified.

5 In these illustrative examples, each coordinate in the plurality of coordinates **458** is a three-dimensional coordinate. The plurality of coordinates **458** may be based on a Cartesian coordinate system, a spherical coordinate system, or some other type of three-dimensional coordinate system. In these illustrative examples, a Cartesian coordinate system with x, y, and z coordinates is used.

10 The plurality of coordinates **458** may be identified using a number of reference points **455** in the images **430**. The number of reference points **455** allows the second number of coordinates **462** for the number of hidden points **448** to be identified.

15 In particular, the reference points in the number of reference points **455** for a mirror unit in the number of mirror units **422** may be used to identify the coordinates for a plane through the mirror unit. In other words, the number of reference points **455** allows the location of the number of mirror units **422** to be identified relative to the object **406** such that the second number of coordinates **462** for the number of hidden points **448** seen in the number of reflections **454** for the number of mirror units **422** may be identified.

20 In some cases, reference points in the number of reference points **455** for a mirror unit may be used to define the plane for the mirror unit. The number of reference points **455** may include points on the number of mirror units **422**, points on a structure or object around the number of mirror units **422**, and/or other suitable points.

25 For example, in these illustrative examples, the number of reference points **455** may be on a number of frames for the number of mirror units **422**. In other illustrative examples, the number of reference points **455** may be on a number of structures around the number of mirror units **422**. As one example, when reference points in the number of reference points **455** are on a number of structures around a mirror unit in the number of mirror units **422**, the number of structures may have known positions relative to the mirror unit. In other words, the positions of the number of structures relative to a plane through the mirror unit may be known.

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In these illustrative examples, the number of reference points **455** may be visible in the images **430**. For example, a set of markers **467** may be positioned on the number of reference points **455** to make the number of reference points **455** visible in the images **430**.

5 The set of markers **467** may include, for example, without limitation, dots projected onto the number of reference points **455** by the laser device **433**, pieces of tape applied to the number of mirror units, paint, tooling balls, and/or other suitable types of markers that may be used to cause the number of reference points **455** to be visible in the images **430**. In some cases, the
10 plurality of markers **432** projected in the form of dots by the laser device **433** may include the set of markers **467**. In this manner, the plurality of markers **432** may include markers on the object **406** and markers for the number of mirror units **422**.

15 With the plurality of coordinates **458**, the measurement module **418** may make additional measurements. For example, the measurement module **418** may compare the plurality of coordinates **458** with a policy **464**. The policy **464** includes a number of rules **466**.

20 Additionally, the policy **464** may also include a number of parameters **468** used in applying the number of rules **466**. In these illustrative examples, the measurement module **418** applies the policy **464** to the plurality of coordinates **458**. The number of rules **466** may be, for example, without limitation, desired ranges for locations of the plurality of points **408**, desired ranges for distances between selected portions of the plurality of points **408**, and/or other suitable types of rules.

25 Further, the measurement module **418** may form a point cloud **469** using the plurality of coordinates **458** for the plurality of points **408**. The point cloud **469** may be a substantially spatially correct point cloud. The plurality of coordinates **458** may form a set of vertices in a coordinate system for the surface **410** of the object **406**.

When the point cloud **469** is substantially spatially correct, points in the point cloud **469** have substantially same locations as corresponding points in the plurality of points **408** on the object **406** when the points in the point cloud **469** are aligned with the corresponding points in the plurality of points **408** on the object **406**. The points in the point cloud **469** may be aligned with corresponding points in the plurality of points **408** on the object **406** by being superimposed on the plurality of points **408**, in one illustrative example.

In other words, when the point cloud **469** is placed over or overlaid on the plurality of points **408** on the object **406**, the points in the point cloud **469** are in substantially the same location as the points in the plurality of points **408**. In this manner, each point in the point cloud **469** for the object **406** corresponds to a point in the plurality of points **408** on the object **406** in a substantially spatially correct manner.

With the point cloud **469**, a model **470** of the object **406** may be formed. The model **470** may be used in making measurements of the object **406**. For example, the policy **464** may be applied to the model **470**. For example, a rule in the number of rules **466** may identify a computer-aided design model **472**. The model **470** may be compared to the computer-aided design model **472**. Differences between the computer-aided design module **472** and the model **470** may be identified for use in determining whether the object **406** meets the policy **464**.

The illustration of the measurement environment **400** in Figure **4** is not meant to imply physical or architectural limitations to the manner in which different advantageous embodiments may be implemented. Other components in addition to and/or in place of the ones illustrated may be used. Some components may be unnecessary in some advantageous embodiments. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined and/or divided into different blocks when implemented in different advantageous embodiments.

For example, although the different advantageous embodiments have been described with respect to making measurements of objects, the different advantageous embodiments may also be used for other purposes. For example, once measurements have been made for the plurality of points **408** to identify the plurality of coordinates **458** for the surface **410** of the object **406**, these coordinates may be used to make the model **470** for other purposes, other than making measurements to determine whether the object **406** meets the policy **464**.

For example, the model **470** may be used to generate additional objects from the object **406**. In other words, the object **406** may form a physical model for making other objects. As another illustrative example, the model **470** may be used in making animations.

In these illustrative examples, the object **406** may take various forms. For example, without limitation, the object **406** may be the aircraft **200** in Figure **2**, an engine, a wing, a wheel, a spar, a chair, a tool, a mold, a person, the ground, or some other suitable type of object **406**.

With reference now to Figure **5**, an illustration of a measurement of hidden points is depicted in accordance with an advantageous embodiment. In this illustrative example, the first camera **314** and the second camera **316** in Figure **3** are positioned relative to the object **304**.

The object **304** has a surface **500**. The mirror unit **312** is positioned behind the object **304** relative to the first camera **314** and the second camera **316**. In this illustrative example, the first camera **314** and the second camera **316** may generate images of a first point **510** to identify the coordinate for the first point **510**.

The first camera **314** has a first line of sight **514** to the first point **510**, and the second camera **316** has a first line of sight **516** to the first point **510**. In other words, the first point **510** is a visible point.

In these illustrative examples, it may also be desirable to identify the coordinates for a second point **518**. The first camera **314** and the second camera **316**, however, do not have a line of sight to the second point **518**. In this illustrative example, the mirror unit **312** is positioned such that the second point **518** can be seen in the reflection on the mirror unit **312** by the first camera **314** and the second camera **316**.

In this illustrative example, the first camera **314** has a second line of sight **520** from the first camera **314** to a point **522** on the mirror unit **312** where a reflection of the second point **518** can be seen in the mirror unit **312**. The second camera **316** has a second line of sight **524** from the second camera **316** to a point **525** on the mirror unit **312** where a reflection of the second point **518** can be seen in the mirror unit **312**.

An intersection **523** of the second line of sight **520** for the first camera **314** and the second line of sight **524** for the second camera **316** occurs at a point **526**. The point **526** is a point in three-dimensional space in these examples. In this illustrative example, the point **526** may be rotated about **180** degrees relative to a plane **530** for the mirror unit **312**. In other words, the point **526** may be inverted across the plane **530** of the mirror unit **312** to form a new point (not shown) such that a line through the point **526** and the new point (not shown) is substantially perpendicular to the plane **530** of the mirror unit **312**.

The location of the point **526** after being rotated about **180** degrees relative to the plane **530** for the mirror unit **312** has a three-dimensional coordinate that is substantially the same as the three-dimensional coordinate for the second point **518**. In other words, the location of the point **526** after being rotated is substantially the same location as the second point **518**.

In this manner, coordinates of the first point **510** and the second point **518** may be measured using images generated by the camera system **308** without having to move or reposition any component in the photogrammetry system **306**.

With reference now to Figure 6, an illustration of a mirror unit is depicted in accordance with an advantageous embodiment. In this illustrative example, the mirror unit **312** in Figure 3 is depicted. The mirror unit **312** includes a mirror **600** and a frame **602**.

In these illustrative examples, the mirror **600** has a surface **601**, which is a reflective surface **603**. In particular, the reflective surface **603** for the mirror **600** is the outermost surface of the mirror **600**. In other words, other layers are not present on or above the reflective surface **603**. For example,
 5 layers of glass, acrylic, and/or other materials are not present between this reflective surface **603** of the mirror **600** and the environment. When the mirror **600** has this type of configuration, the mirror **600** is referred to as a first surface mirror.

Of course, in other examples, other types of the mirror **600** may be used. For example, the surface **601** of the mirror **600** may not be reflective.
 10 In particular, the surface **601** may be glass and/or a coating material. When the mirror **600** has this type of configuration, the mirror **600** is referred to as a second surface mirror. With this configuration for the mirror **600**, the thickness from the surface **601** of the mirror **600** to a layer having the
 15 reflective material in the mirror **600** is identified. This thickness is taken into account in identifying coordinates for the points **320** on the object **304** in Figure 3.

As illustrated, the frame **602** is associated with the mirror **600**. The frame **602** surrounds the mirror **600** and is configured to hold the mirror **600**.
 20 In this illustrative example, the frame **602** has a first side **604** and a second side **606**. A surface **608** of the first side **604** of the frame **602** is configured to be substantially coplanar with the mirror **600**. In other words, the surface **601** of the mirror **600** and the surface **608** of the first side **604** of the frame **602** lie in substantially the same plane, such as the plane **530** in Figure 5.

The frame **602** may be used to identify the position of the mirror **600** relative to an object, such as the object **304** in Figure 3 and Figure 5. For example, the scanner **310** in Figure 3 projects the dots **319** onto the surface **608** of the frame **602** at the same time that the dots **319** are projected on the object **304** in Figure 3 and Figure 5. The dots **319** on the surface **608** of the
 25 frame **602** are used to identify the position of the plane through the frame **602** in three-dimensional space in these illustrative examples. When used in this manner, the dots **319** on the surface **608** of the frame **602** cause reference points on the surface **608** of the frame **602** to be visible in the images generated.
 30

In this manner, the position of the surface **601** of the mirror **600** may also be identified because the surface **608** of the first side **604** of the frame **602** and the surface **601** of the mirror **600** are substantially coplanar. The dots **319** projected onto the surface **601** of the mirror **600** may not be used to identify the position of the mirror **600** because the mirror **600** reflects light.

Of course, in other illustrative examples, reference points for identifying the position of the surface **601** of the mirror **600** may be made visible using other techniques. For example, a frame **602** may be absent in the mirror unit **312**. Instead, the mirror unit **312** may comprise the mirror **600** and a number of pieces of tape on the mirror **600**.

The pieces of tape prevent light from being reflected at the locations of the pieces of tape on the mirror **600**. In this manner, the dots **319** projected onto the pieces of tape may be on reference points that may be used for identifying the position of the surface **601** of the mirror **600**. In some illustrative examples, paint, labels, tags, and/or other suitable types of markers may be placed on the reference points on the mirror **600**.

In yet other illustrative example, reference points on tooling balls may be used with the mirror **600**. Dots **319** projected onto the tooling balls may allow the reference points to be visible. For example, a height of a tooling ball from a base or table on which the mirror **600** is placed to a center of the tooling ball may be known. In particular, this height along with a radius of the tooling ball and the dots **319** projected onto the tooling ball may be used to identify the position of the surface **601** of the mirror.

In this manner, any item connected to or attached to the mirror **600** may be used to provide markers on the reference points on the mirror **600** for identifying a position of the surface **601** of the mirror when the dimensions and/or coordinates for the item are known.

Turning now to Figure 7, an illustration of a cross-sectional view of the mirror unit **312** is depicted in accordance with an advantageous embodiment. In this illustrative example, a cross-sectional view of the mirror unit **312** is depicted taken along lines 7-7 in Figure 6.

With reference now to Figure 8, an illustration of a point cloud for a measurement environment is depicted in accordance with an advantageous embodiment. In this illustrative example, a point cloud **800** is an example of one implementation for the point cloud **469** in Figure 4. The point cloud **800** is generated by a measurement module, such as the measurement module **418** in Figure 4 for the measurement environment **300** in Figure 3.

In this depicted example, the point cloud **800** is a set of vertices in a three-dimensional coordinate system that represents the surface of the object **304** and other features within the measurement environment **300** in Figure 3. These other features may include any structures, objects, and/or other components in the images generated by the camera system **308** other than object **304** in Figure 3.

As illustrated, the point cloud **800** includes circular points **802** and rectangular points **804**. In this illustrative example, the circular points **802** are generated for the visible portion **323** of the points **320** on the object **304** in Figure 3. The circular points **802** are in locations in the three-dimensional coordinate system for the point cloud **800** that correspond to the locations of the visible portion **323** of the points **320** on the object **304** in Figure 3.

Further, the rectangular points **804** are generated for the hidden portion **322** of the points **320** on the object **304** in Figure 3. A portion of the rectangular points **804** forms a first group of points **806** in the point cloud **800**. The first group of points **806** in the point cloud **800** are in locations in the three-dimensional coordinate system that correspond to the intersections of first lines of sight for the first camera **314** and second lines of sight for the second camera **316**. The first lines of sight are between the first camera **314** and the points on the mirror unit **312** where the reflections of the hidden portion **322** of the points **320** on the object **304** can be seen on the mirror unit **312**. The second lines of sight are between the second camera **316** and the points **320** on the mirror unit **312** where the reflections of the hidden portion **322** of the points **320** on the object **304** can be seen on the mirror unit **312**.

As one illustrative example, a rectangular point **810** in the first group of points **806** is in a location in the point cloud **800** that corresponds to the location of the point **526** in Figure 5. In other words, the rectangular point **810** is in a location that corresponds to the intersection of the second line of sight **520** for the first camera **314** in Figure 5 and the second line of sight **524** for the second camera **316** in Figure 5.

In this illustrative example, the plane formed by lines **812** represents the plane **530** for the mirror unit **312** in Figure 5. A second group of points **814** in the point cloud **800** are formed by rotating the first group of points **806** by about **180** degrees relative to the plane formed by the lines **812**. The second group of points **814** is in locations in the three-dimensional coordinate system for the point cloud **800** that corresponds to the locations of the hidden portion **322** of the points **320** on the object **304** in Figure 3.

In this manner, three-dimensional coordinates may be generated for both the visible portion **323** and the hidden portion **322** of points **320** on the object **304** in Figure 3.

With reference now to Figure 9, an illustration of a flowchart of a process for making measurements for an object is depicted in accordance with an advantageous embodiment. The process illustrated in Figure 9 may be implemented using the measurement system **402** in Figure 4.

The process begins by placing a number of cameras **420** for a camera system **414** in a plurality of positions **440** relative to an object **406** (operation **900**). The camera system **414** is part of a measurement system **402**, which is a photogrammetry system **412** in these illustrative examples. In this illustrative example, the number of cameras **420** is two cameras. However, in other illustrative examples, the number of cameras **420** may be one, three, or some other suitable number of cameras.

A first portion **442** of a plurality of points **408** on a surface **410** of the object **406** is visible to the camera system **414**. This first portion **442** of the plurality of points **408** is a number of visible points **444**. Images **430** of the object **406** generated by the camera system **414** include the number of visible points **444**.

5 Thereafter, a number of mirror units **422** are placed in a number of positions **452** relative to the object **406** (operation **902**). In this illustrative example, one mirror unit is positioned relative to the object **406**. The number of positions **452** for the number of mirror units **422** is selected such that a second portion **446** of the plurality of points **408** on the surface **410** of the object **406** that are hidden to the camera system **414** have a number of reflections **454** on the number of mirror units **422** that are seen in the images **430** generated by the camera system **414**. This second portion **446** of the plurality of points **408** on the surface **410** of the object **406** that is hidden to the camera system **414** is a number of hidden points **448**.

10 Next, a plurality of markers **432** is projected on the plurality of points **408** on the surface **410** of the object **406** using a laser device **433** (operation **904**). The plurality of markers **432** are dots, such as the dots **319** in Figure 3, in this illustrative example. Then, the camera system **414** generates images **430** of the object **406** (operation **906**). These images **430** include the number of visible points **444** and the number of reflections **454** of the number of hidden points **448** on the number of mirror units **422**.

15 A measurement module **418** identifies a plurality of coordinates **458** for the plurality of points **408** on the surface **410** of the object **406** from the images **430** (operation **908**). The plurality of coordinates are identified for both the number of visible points **444** on the surface **410** of the object **406** and the number of hidden points **448** on the surface **410** of the object **406**. In this illustrative example, the plurality of coordinates are three-dimensional coordinates based on a Cartesian coordinate system.

20 Operation **908** may be performed using a number of reference points **455** for the number of mirror units **422**. The number of reference points **455** are visible in the images **430**.

25 Thereafter, the measurement module **418** applies a policy **464** to the plurality of coordinates **458** identified for the plurality of points **408** on the object **406** (operation **910**). In operation **910**, the measurement module **418** compares the plurality of coordinates **458** to a number of rules **466** and/or criteria specified in the policy **464**.

5 The measurement module **418** then makes measurements **404** for the object **406** based on the comparisons between the plurality of coordinates **458** and the policy **464** (operation **912**), with the process terminating thereafter. These measurements **404** may include, for example, whether or not the object **406** meets the policy **464** within tolerances, how closely the locations for the plurality of points **408** on the object **406** are to desirable ranges for the plurality of points **406** on the object **406**, and/or other suitable types of measurements.

10 With reference now to Figure **10**, an illustration of a flowchart of a process for identifying a coordinate for a hidden point on an object is depicted in accordance with an advantageous embodiment. The process illustrated in Figure **10** may be used in implementing operation **908** in Figure **9** to identify coordinates for the plurality of points **408** on the surface **410** of the object **406**. Further, this process may be implemented using measurement module **418** in
15 Figure **4**.

The process begins by identifying a reflection in the number of reflections **454** of a hidden point in the number of hidden points **448** on a mirror unit in the number of mirror units **422** in the images **430** generated by each of the number of cameras **420** (operation **1000**).

20 The process identifies a line of sight between each of the number of cameras **420** and the corresponding reflection of the hidden point on the mirror unit (operation **1002**). As one illustrative example, the lines of sight identified in operation **1002** may be, for example, second line of sight **520** for camera **314** and second line of sight **524** for camera **316** in Figure **5**.
25 Operation **1002** may be performed based on an identification of the plurality of positions **440** for the number of cameras **420** and the position in the number of positions **452** of the mirror unit.

30 Next, the process identifies the intersection of the lines of sight between the number of cameras **420** and the corresponding reflections of the hidden point on the mirror unit (operation **1004**). The intersection may be, for example, the intersection **523** in Figure **5**.

The process then rotates a point at which the intersection of the lines of sight occurs about **180** degrees relative to a plane through the mirror unit to form a new point (operation **1006**). The point at which the intersection occurs may be, for example, point **526** in Figure 5.

5 Thereafter, the process identifies the coordinates for the new point (operation **1008**), with the process terminating thereafter. The coordinates for the new point correspond to the location of the hidden point on the object **406**. In other words, in operation **1008**, the process identifies the coordinates for the hidden point on the surface **410** of the object **406**.

10 The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatus and methods in different advantageous embodiments. In this regard, each block in the flowchart or block diagrams may represent a module, segment, function, and/or a portion
15 of an operation or step. For example, one or more of the blocks may be implemented as program code, in hardware, or a combination of the program code and hardware. When implemented in hardware, the hardware may, for example, take the form of integrated circuits that are manufactured or configured to perform one or more operations in the flowcharts or block
20 diagrams.

 In some alternative implementations, the function or functions noted in the block may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order,
25 depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

For example, in some illustrative examples, the number of cameras **420** used in operation **900** in Figure 9 may be one camera. When only one camera is used, operation **900** may be performed together with operation **906** after operation **904** in Figure 9. For example, after operation **904**, the camera may be placed in one position in the plurality of positions **440** in operation **900** and then an image of the images **430** of the object **406** may be generated in operation **906** in Figure 9. Thereafter, the camera may be moved into another position in the plurality of positions **440** to generate another image of the object **406**.

In this manner, in operation **900** and operation **906** in Figure 9, the camera may be moved to the different positions in the plurality of positions **440** to generate the images **430** of the object.

Thus, the different advantageous embodiments provide a method and apparatus for making measurements for an object **406**. In one advantageous embodiment, an apparatus comprises a number of mirror units **422**, a number of cameras **420**, and a measurement module **418**. The number of mirror units **422** is configured to be positioned relative to the object **406**. The number of cameras **420** is configured to generate images **430** of the object **406** and the number of mirror units **422** in which a plurality of points **408** on the object **406** is present in the images **430**.

A first portion **442** of the plurality of points **408** is visible to the number of cameras **420** on the object **406**. A second portion **446** of the plurality of points **408** is hidden to the number of cameras **420**. A number of reflections **454** of the second portion **446** of the plurality of points **408** is visible on the number of mirror units **422** in the images **430**. The measurement module **418** is configured to identify a plurality of coordinates **458** for the plurality of points **408** using the images **430**, a plurality of positions **440** for the number of cameras **420** relative to the object **406**, and a number of positions **452** for the number of mirror units **422**.

In this manner, the different advantageous embodiments provide a measurement system **402** configured to identify the plurality of coordinates **458** for both a number of visible points **444** and a number of hidden points **448** on the surface **410** of the object **406** without needing to move the camera system **414** generating the images **430** of the object **406**, or any other components of the measurement system **402**. This type of measurement system **402** reduces the overall time and effort needed for making measurements of objects.

Turning now to Figure **11**, an illustration of a data processing system is depicted in accordance with an advantageous embodiment. In this illustrative example, a data processing system **1100** may be used in implementing the computer system **456** in Figure **4**. As depicted, the data processing system **1100** includes a communications fabric **1102**, which provides communications between a processor unit **1104**, a memory **1106**, a persistent storage **1108**, a communications unit **1110**, an input/output (I/O) unit **1112**, and a display **1114**.

The processor unit **1104** serves to execute instructions for software that may be loaded into the memory **1106**. The processor unit **1104** may be a number of processors, a multi-processor core, or some other type of processor, depending on the particular implementation. A number, as used herein with reference to an item, means one or more items. Further, the processor unit **1104** may be implemented using a number of heterogeneous processor systems in which a main processor is present with secondary processors on a single chip.

The memory **1106** and the persistent storage **1108** are examples of storage devices **1116**. A storage device is any piece of hardware that is capable of storing information, such as, for example, without limitation, data, program code in functional form, and/or other suitable information either on a temporary basis and/or a permanent basis. The storage devices **1116** may also be referred to as computer readable storage devices in these examples. The memory **1106**, in these examples, may be, for example, a random access memory or any other suitable volatile or non-volatile storage device. The persistent storage **1108** may take various forms, depending on the particular implementation.

For example, the persistent storage **1108** may contain one or more components or devices. For example, the persistent storage **1108** may be a hard drive, a flash memory, a rewritable optical disk, a rewritable magnetic tape, or some combination of the above. The media used by the persistent storage **1108** may also be removable. For example, a removable hard drive may be used for the persistent storage **1108**.

The communications unit **1110**, in these examples, provides for communications with other data processing systems or devices. In these examples, the communications unit **1110** is a network interface card. The communications unit **1110** may provide communications through the use of either or both physical and wireless communications links.

The input/output unit **1112** allows for input and output of data with other devices that may be connected to the data processing system **1100**. For example, the input/output unit **1112** may provide a connection for user input through a keyboard, a mouse, and/or some other suitable input device. Further, the input/output unit **1112** may send output to a printer. The display **1114** provides a mechanism to display information to a user.

Instructions for the operating system, applications, and/or programs may be located in the storage devices **1116**, which are in communication with the processor unit **1104** through the communications fabric **1102**. In these illustrative examples, the instructions are in a functional form on the persistent storage **1108**. These instructions may be loaded into the memory **1106** for execution by the processor unit **1104**. The processes of the different advantageous embodiments may be performed by the processor unit **1104** using computer implemented instructions, which may be located in a memory, such as the memory **1106**.

These instructions are referred to as program code, computer usable program code, or computer readable program code that may be read and executed by a processor in the processor unit **1104**. The program code in the different advantageous embodiments may be embodied on different physical or computer readable storage media, such as the memory **1106** or the persistent storage **1108**.

Program code **1118** is located in a functional form on a computer readable media **1120** that is selectively removable and may be loaded onto or transferred to the data processing system **1100** for execution by the processor unit **1104**. The program code **1118** and the computer readable media **1120** form a computer program product **1122** in these examples. In one example, the computer readable media **1120** may be a computer readable storage media **1124** or a computer readable signal media **1126**. The computer readable storage media **1124** may include, for example, an optical or magnetic disk that is inserted or placed into a drive or other device that is part of the persistent storage **1108** for transfer onto a storage device, such as a hard drive, that is part of the persistent storage **1108**. The computer readable storage media **1124** may also take the form of a persistent storage, such as a hard drive, a thumb drive, or a flash memory, that is connected to the data processing system **1100**.

Alternatively, the program code **1118** may be transferred to the data processing system **1100** using the computer readable signal media **1126**. The computer readable signal media **1126** may be, for example, a propagated data signal containing the program code **1118**. For example, the computer readable signal media **1126** may be an electromagnetic signal, an optical signal, and/or any other suitable type of signal. These signals may be transmitted over communications links, such as wireless communications links, optical fiber cable, coaxial cable, a wire, and/or any other suitable type of communications link.

The different components illustrated for the data processing system **1100** are not meant to provide architectural limitations to the manner in which different advantageous embodiments may be implemented. The different advantageous embodiments may be implemented in a data processing system including components in addition to or in place of those illustrated for the data processing system **1100**.

Other components shown in Figure 11 can be varied from the illustrative examples shown. The different embodiments may be implemented using any hardware device or system capable of running program code. As one example, the data processing system may include organic components integrated with inorganic components and/or may be comprised entirely of organic components excluding a human being. For example, a storage device may be comprised of an organic semiconductor.

In another illustrative example, the processor unit **1104** may take the form of a hardware unit that has circuits that are manufactured or configured for a particular use. This type of hardware may perform operations without needing program code to be loaded into a memory from a storage device to be configured to perform the operations.

For example, when the processor unit **1104** takes the form of a hardware unit, the processor unit **1104** may be a circuit system, an application specific integrated circuit (ASIC), a programmable logic device, or some other suitable type of hardware configured to perform a number of operations. With a programmable logic device, the device is configured to perform the number of operations. The device may be reconfigured at a later time or may be permanently configured to perform the number of operations.

Examples of programmable logic devices include, for example, a programmable logic array, programmable array logic, a field programmable logic array, a field programmable gate array, and other suitable hardware devices. With this type of implementation, the program code **1118** may be omitted because the processes for the different advantageous embodiments are implemented in a hardware unit.

In still another illustrative example, the processor unit **1104** may be implemented using a combination of processors found in computers and hardware units. The processor unit **1104** may have a number of hardware units and a number of processors that are configured to run the program code **1118**. With this depicted example, some of the processes may be implemented in the number of hardware units, while other processes may be implemented in the number of processors.

5 In another example, a bus system may be used to implement the communications fabric **1102** and may be comprised of one or more buses, such as a system bus or an input/output bus. Of course, the bus system may be implemented using any suitable type of architecture that provides for a transfer of data between different components or devices attached to the bus system.

10 In the above described embodiments, an apparatus is described that includes a number of mirror units configured to be positioned relative to an object, a number of cameras configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images, wherein a first portion of the plurality of points on the object is visible on the object in the images and a second portion of the plurality of points on the object is visible on the number of mirror units in the images, and a measurement module configured to identify a plurality of coordinates for the plurality of points using the images, a plurality of positions for the number of cameras relative to the object, a number of reference points in the images, and a number of positions for the number of mirror units in which the plurality of coordinates for the plurality of points on the object are used to form a substantially spatially correct point cloud for the object.

20 In embodiments, such an apparatus may include a laser device configured to generate a plurality of markers on the plurality of points, wherein the plurality of markers on the plurality of points is visible in the images.

25 In embodiments, a mirror unit in the number of mirror units includes a mirror having a first surface, and a frame surrounding the mirror and having a second surface, wherein the frame is configured to hold the mirror such that the first surface is substantially coplanar with the second surface and wherein at least a portion of the number of reference points are on the frame in the images.

In identifying the plurality of coordinates for the plurality of points using the images, the measurement module is configured to identify an intersection of lines of sight for the number of cameras, wherein each of the lines of sight is between a camera in the number of cameras and a reflection of a point in the second portion of the plurality of points on a mirror unit in the number of mirror units; rotate the point at which the intersection occurs about 180 degrees relative to a plane for the mirror unit to form a new point, and identify a coordinate for the new point.

As described above, in embodiments of the measurement module is configured to apply a policy to the plurality of coordinates for the plurality of points. In specific embodiments, points in the substantially spatially correct point cloud have substantially same locations as corresponding points in the plurality of points on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the plurality of points on the object. In embodiments, the measurement module is configured to generate a model of the object using the substantially spatially correct point cloud, while in specific embodiments, the measurement module is configured to compare the model of the object with another model of the object and identify a number of differences between the model of the object and the another model of the object.

In certain apparatus embodiments, a line of sight for a camera in the number of cameras between the camera and a point in the second portion of the plurality of points is absent. Further, in the first portion of the plurality of points is a number of visible points and the second portion of the plurality of points is a number of hidden points in which the number of hidden points are hidden from a direct view of the number of cameras.

The above description further provides a method for making measurements that includes generating images of an object, and identifying a plurality of coordinates for a plurality of points on a surface of the object from the images using a number of reference points in the images, wherein a first portion of the plurality of points on the object is visible on the object in the images, a second portion of the plurality of points on the object is visible on the number of mirror units in the images.

The method may further include generating a plurality of markers on the plurality of points on the surface of the object using a laser device. In certain embodiment of the method, the generating step is performed using a number of cameras and wherein the step of identifying the plurality of
5 coordinates for the plurality of points on the surface of the object from the images and includes identifying an intersection of lines of sight for the number of cameras, wherein each of the lines of sight is between a camera in the number of cameras and a reflection of a point in the second portion of the plurality of points on a mirror unit in the number of mirror units, rotating the
10 point at which the intersection occurs about **180** degrees relative to a plane for the mirror unit to form a new point, and identifying a coordinate for the new point.

The method may further include generating a substantially spatially correct point cloud for the object using the plurality of coordinates for the
15 plurality of points, wherein points in the substantially spatially correct point cloud have substantially same locations as corresponding points in the plurality of points on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the plurality of points on the object. Additionally, such an embodiment may further include
20 generating a model for the object using the substantially spatially correct point cloud as well as comparing the model of the object with another model of the object, and identifying a number of differences between the model of the object and the another model of the object.

In a specific embodiment, the method includes placing the number of
25 mirror units in a number of positions such that the second portion of the plurality of points is visible on the number of mirror units in the images, wherein a mirror unit in the number of mirror units comprises a mirror having a first surface and a frame surrounding the mirror and having a second surface, wherein the frame is configured to hold the mirror such that the first surface is
30 substantially coplanar with the second surface and wherein at least a portion of the number of reference points are on the frame in the images.

In one specific embodiment of the method, the generating step is performed using a number of cameras and wherein a line of sight for a camera in the number of cameras between the camera and a point in the second portion of the plurality of points is absent.

5 In an embodiment of the method the first portion of the plurality of points is a number of visible points and the second portion of the plurality of points is a number of hidden points in which the number of hidden points is hidden from a direct view of a number of cameras configured to generate the images of the object.

10 In one embodiment, an alternative apparatus is described that includes a number of mirror units configured to be positioned relative to an object, a number of cameras configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images, and a measurement module configured to identify a plurality of
15 coordinates for the plurality of points using a number of reference points in the images, a first portion of the plurality of points on the object visible on the object in the images, and a second portion of the plurality of points on the object visible on the number of mirror units in the images.

20 The description of the different advantageous embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the advantageous embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous
25 embodiments. The advantageous embodiment or embodiments selected are chosen and described in order to best explain the principles of the advantageous embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

30

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. An apparatus comprising:

5

a number of mirror units configured to be positioned relative to an object;

10

a number of cameras configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images, wherein a first portion of the plurality of points on the object is visible on the object in the images and a second portion of the plurality of points on the object is visible on the number of mirror units in the images; and

15

a measurement module configured to identify a plurality of coordinates for the plurality of points using the images, a plurality of positions for the number of cameras relative to the object, a number of reference points in the images, and a number of positions for the number of mirror units in which the plurality of coordinates for the plurality of points on the object are used to form a substantially spatially correct point cloud for the object.

2. The apparatus of claim 1 further comprising:

20

a laser device configured to generate a plurality of markers on the plurality of points, wherein the plurality of markers on the plurality of points is visible in the images.

3. The apparatus of claim 1, wherein a mirror unit in the number of mirror units comprises:

25

a mirror having a first surface; and

a frame surrounding the mirror and having a second surface, wherein the frame is configured to hold the mirror such that the first surface is substantially coplanar with the second surface and wherein at least a portion of the number of reference points are on the frame in the images.

5

4. The apparatus of claim 1, wherein in identifying the plurality of coordinates for the plurality of points using the images, the measurement module is configured to:

identify an intersection of lines of sight for the number of cameras, wherein each of the lines of sight is between a camera in the number of cameras and a reflection of a point in the second portion of the plurality of points on a mirror unit in the number of mirror units;

10

rotate the point at which the intersection occurs about **180** degrees relative to a plane for the mirror unit to form a new point; and

15

identify a coordinate for the new point.

5. The apparatus of claim 1, wherein the measurement module is configured to apply a policy to the plurality of coordinates for the plurality of points.

6. The apparatus of claim 1, wherein points in the substantially spatially correct point cloud have substantially same locations as corresponding points in the plurality of points on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the plurality of points on the object.

20

7. The apparatus of claim 6, wherein the measurement module is configured to generate a model of the object using the substantially spatially correct point cloud.

25

8. The apparatus of claim 7, wherein the measurement module is configured to compare the model of the object with another model of the object and identify a number of differences between the model of the object and the another model of the object.
- 5 9. The apparatus of claim 1, wherein a line of sight for a camera in the number of cameras between the camera and a point in the second portion of the plurality of points is absent.
- 10 10. The apparatus of claim 1, wherein the first portion of the plurality of points is a number of visible points and the second portion of the plurality of points is a number of hidden points in which the number of hidden points are hidden from a direct view of the number of cameras.
11. A method for making measurements, the method comprising:
 - generating images of an object;
 - 15 identifying a plurality of coordinates for a plurality of points on a surface of the object from the images using a number of reference points in the images, wherein a first portion of the plurality of points on the object is visible on the object in the images, a second portion of the plurality of points on the object is visible on a number of mirror units in the images; and
 - 20 generating a substantially spatially correct point cloud for the object using the plurality of coordinates for the plurality of points, wherein points in the substantially spatially correct point cloud have substantially same locations as corresponding points in the plurality of points on the object when the points in the substantially spatially correct point cloud are aligned with the corresponding points in the
 - 25 plurality of points on the object.
12. The method of claim 11 further comprising:

generating a plurality of markers on the plurality of points on the surface of the object using a laser device.

- 5 **13.** The method of claim **11**, wherein the generating step is performed using a number of cameras and wherein the step of identifying the plurality of coordinates for the plurality of points on the surface of the object from the images comprises:

10 identifying an intersection of lines of sight for the number of cameras, wherein each of the lines of sight is between a camera in the number of cameras and a reflection of a point in the second portion of the plurality of points on a mirror unit in the number of mirror units;

 rotating the point at which the intersection occurs about **180** degrees relative to a plane for the mirror unit to form a new point; and

15 identifying a coordinate for the new point.

- 14.** The method of claim **11** further comprising:

 generating a model for the object using the substantially spatially correct point cloud.

- 15.** The method of claim **14** further comprising:

20 comparing the model of the object with another model of the object; and

 identifying a number of differences between the model of the object and the another model of the object.

16. The method of claim 11 wherein a mirror unit in the number of mirror units comprises a mirror having a first surface and a frame surrounding the mirror and having a second surface, wherein the frame is configured to hold the mirror such that the first surface is substantially coplanar with the second surface and wherein at least a portion of the number of reference points are on the frame in the images.

17. The method of claim 11, wherein the generating step is performed using a number of cameras and wherein a line of sight for a camera in the number of cameras between the camera and a point in the second portion of the plurality of points is absent.

18. The method of claim 11, wherein the first portion of the plurality of points is a number of visible points and the second portion of the plurality of points is a number of hidden points in which the number of hidden points is hidden from a direct view of a number of cameras configured to generate the images of the object.

19. An apparatus comprising:

a number of mirror units configured to be positioned relative to an object;

a number of cameras configured to generate images of the object and the number of mirror units in which a plurality of points on the object is present in the images; and

5 a measurement module configured to identify a plurality of
coordinates for the plurality of points using a number of reference
points in the images, a first portion of the plurality of points on the
object visible on the object in the images, and a second portion of
the plurality of points on the object visible on the number of mirror
units in the images, and configured to generate a point cloud for the
object using the plurality of coordinates for the plurality of points,
wherein points in the point cloud have substantially the same
locations as corresponding points in the plurality of points on the
10 object when the points in the point cloud are aligned with the
corresponding points in the plurality of points on the object.

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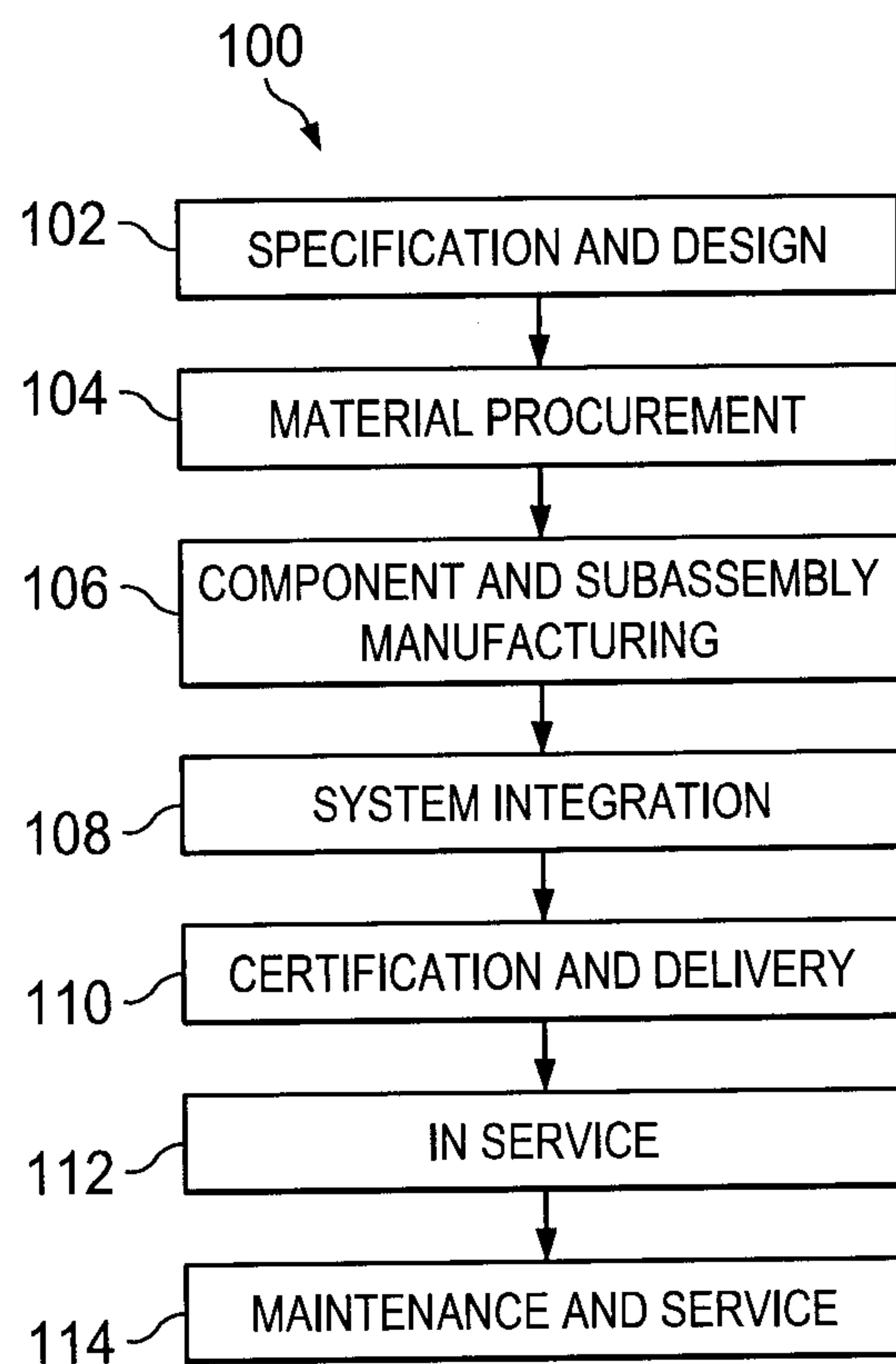


FIG. 1

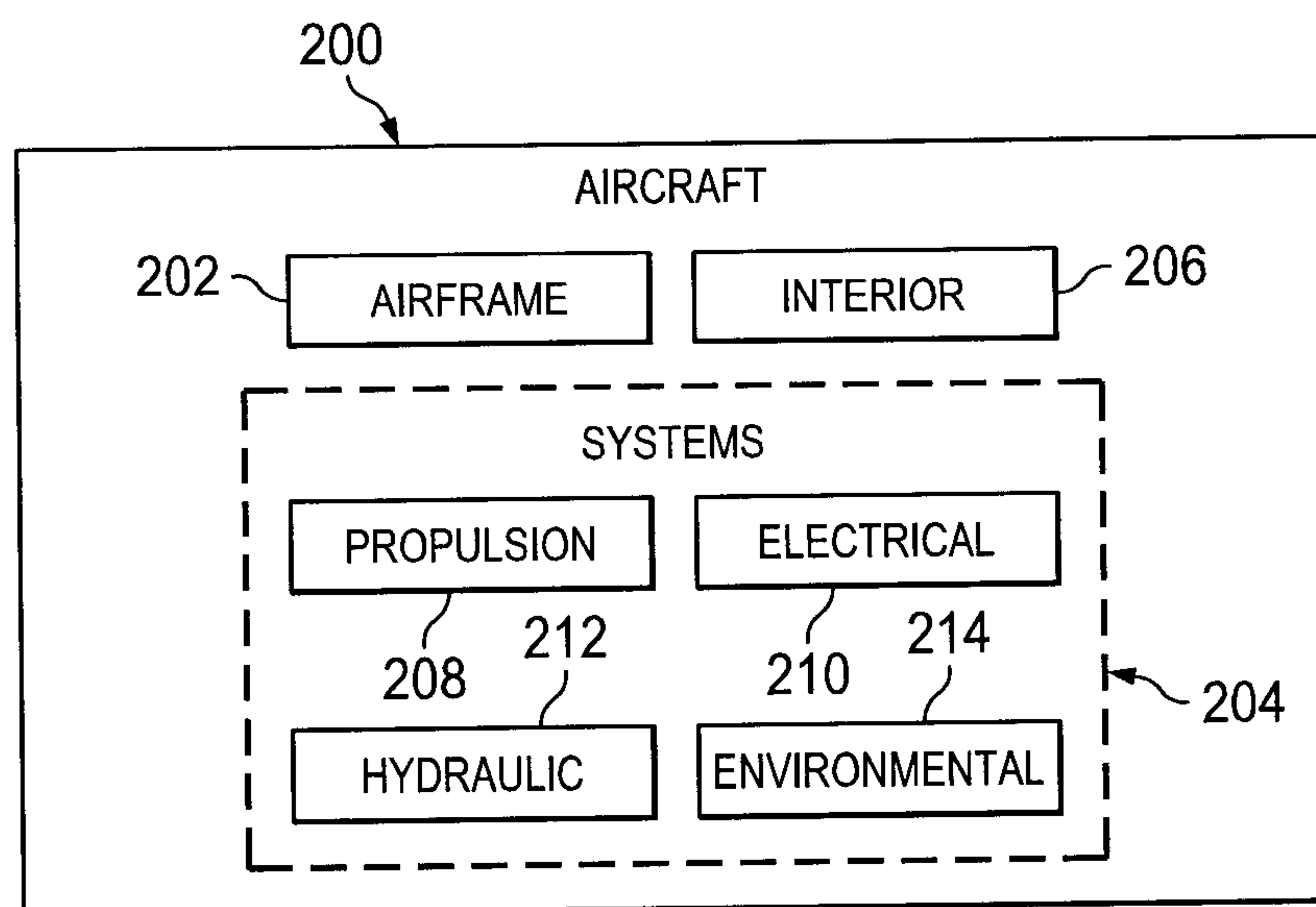


FIG. 2

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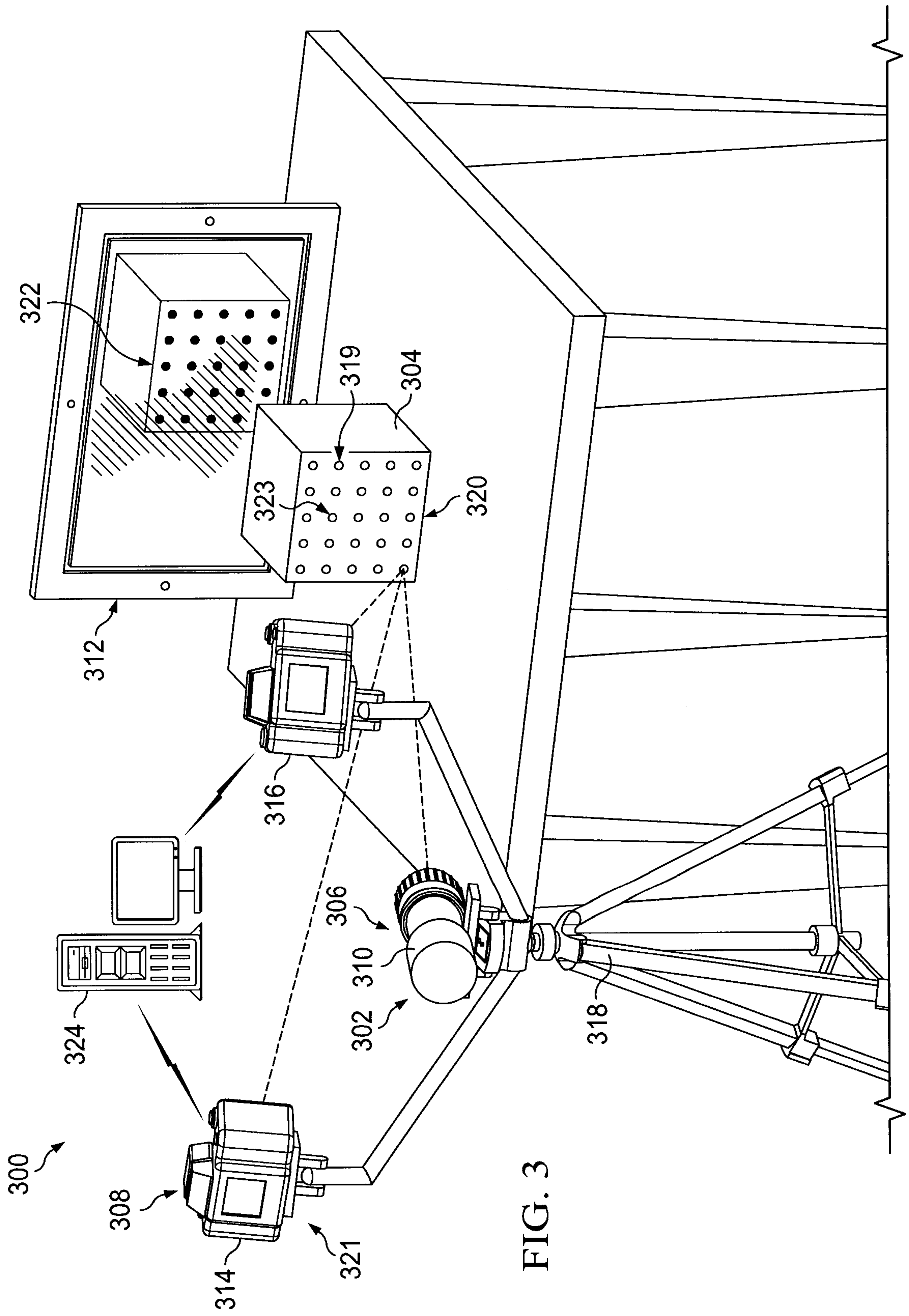
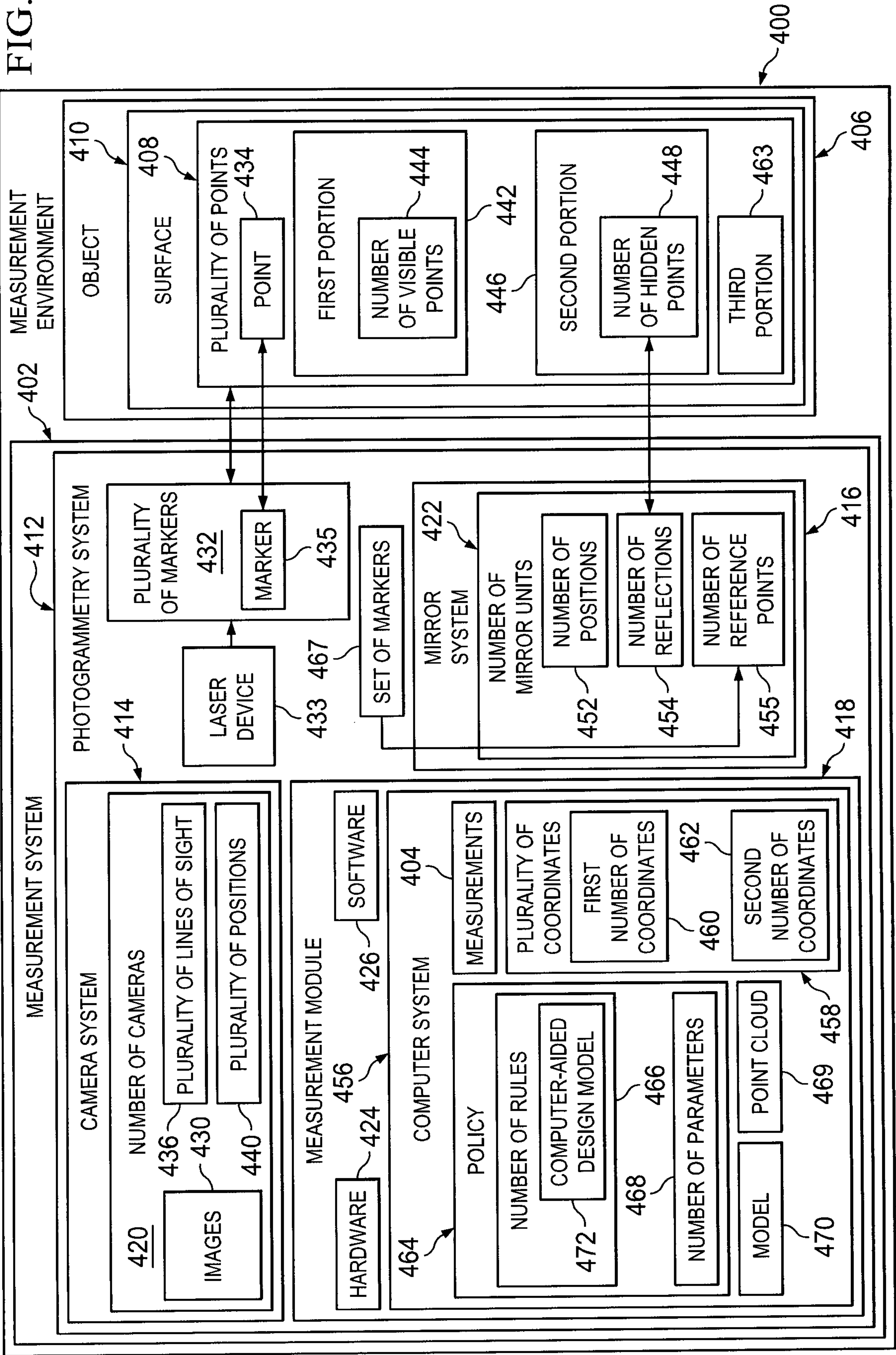


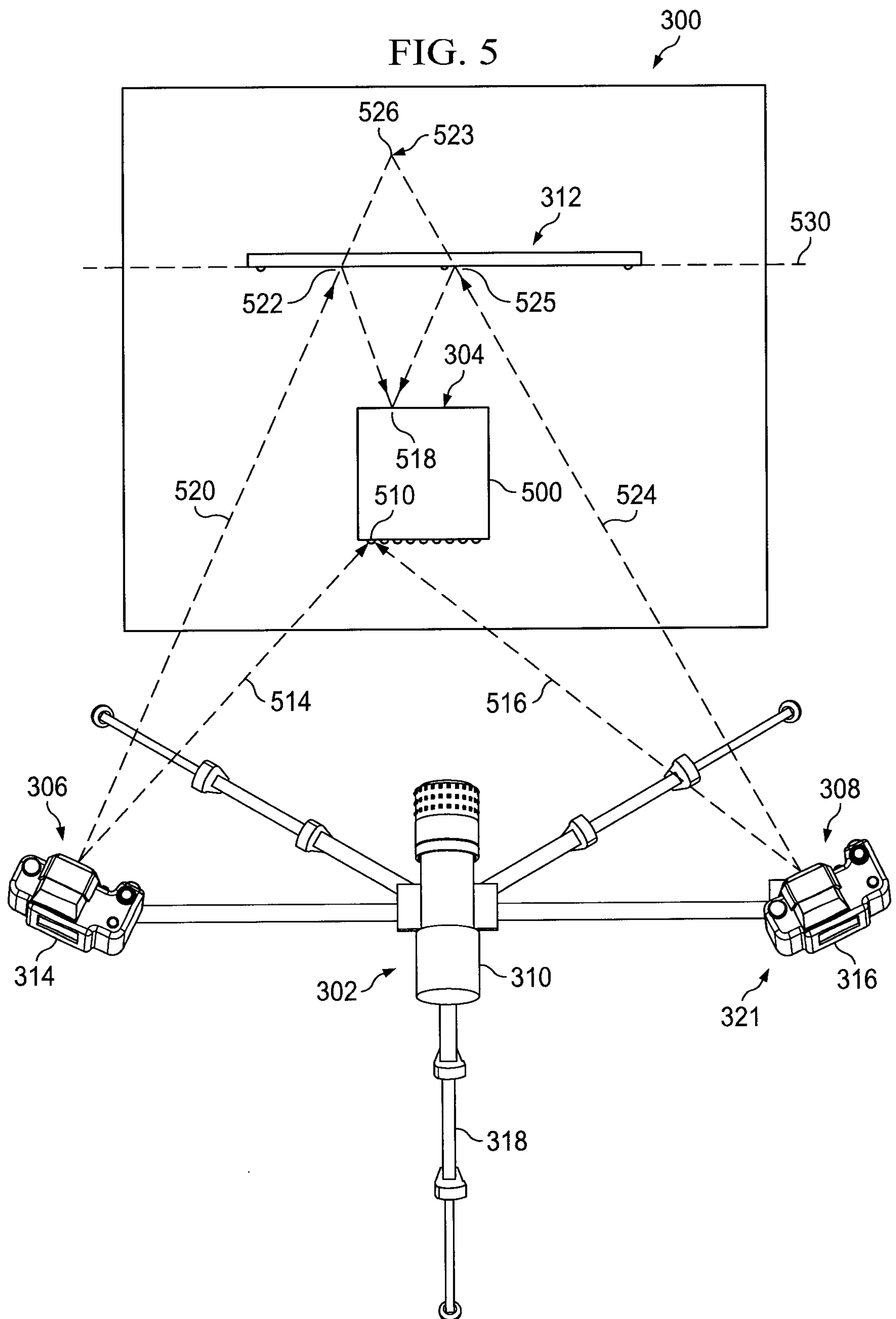
FIG. 3

FIG. 4



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FIG. 5



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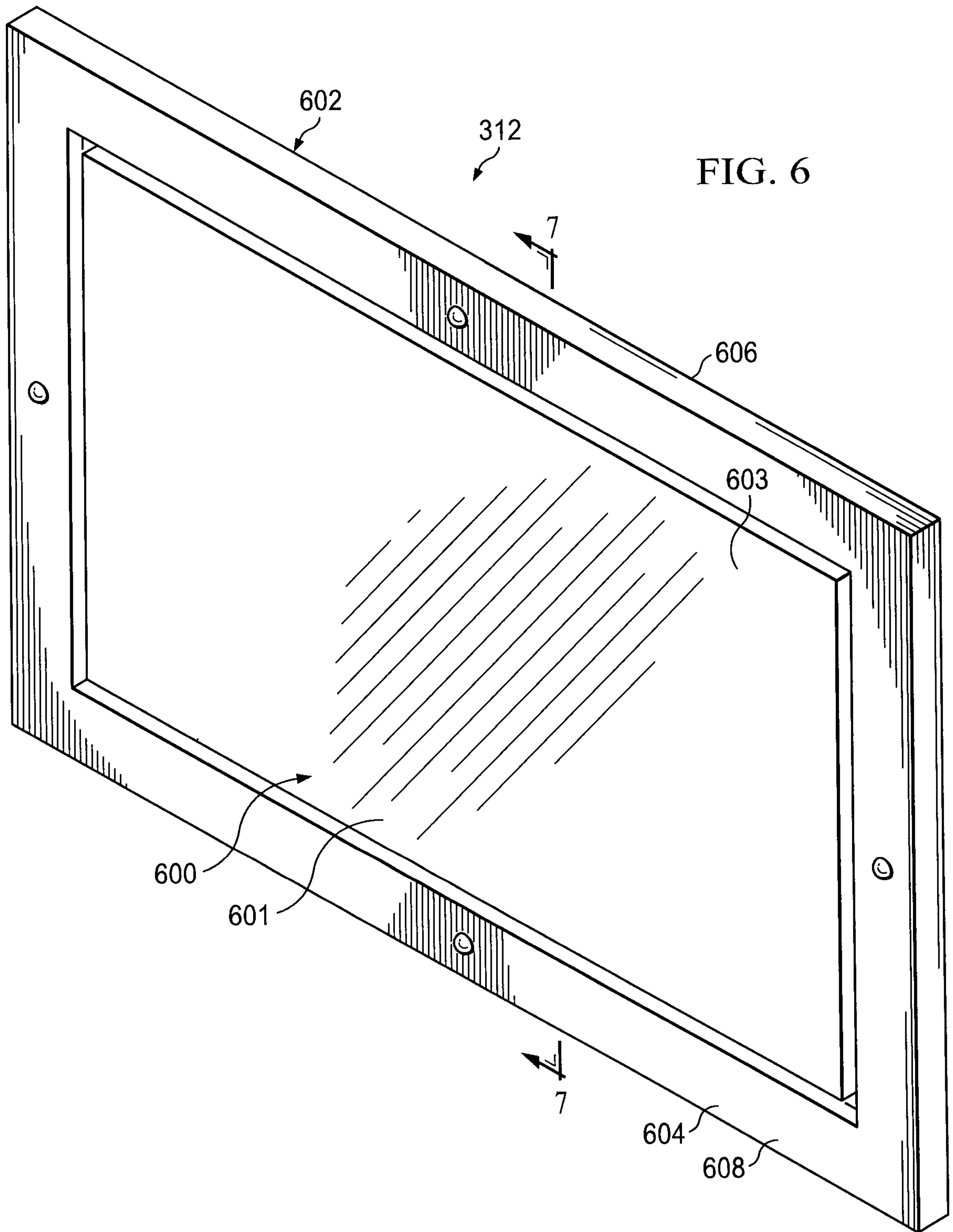


FIG. 7

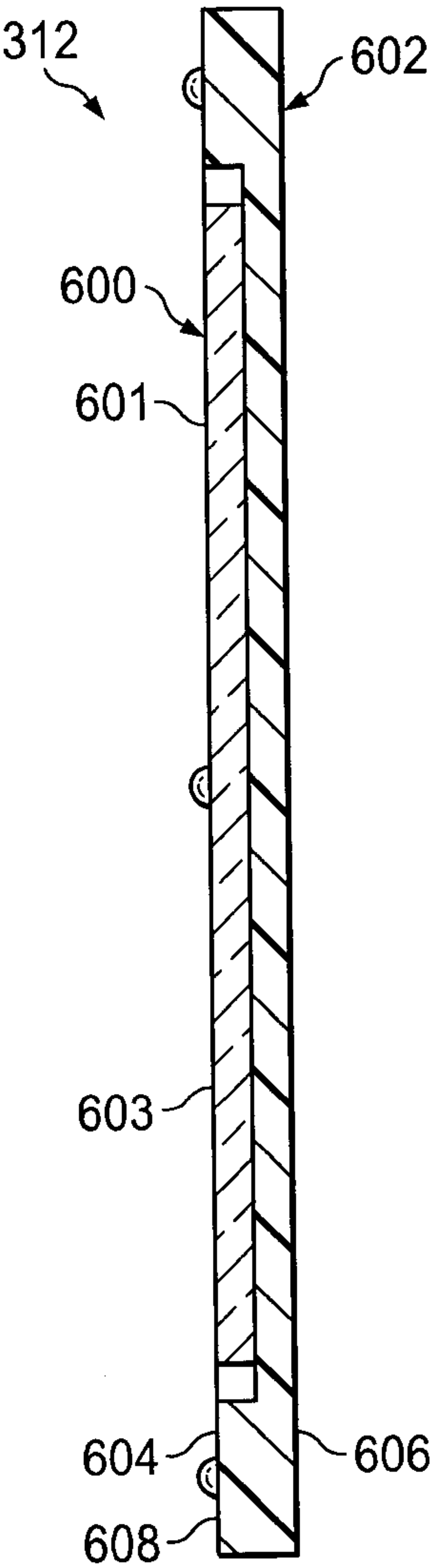
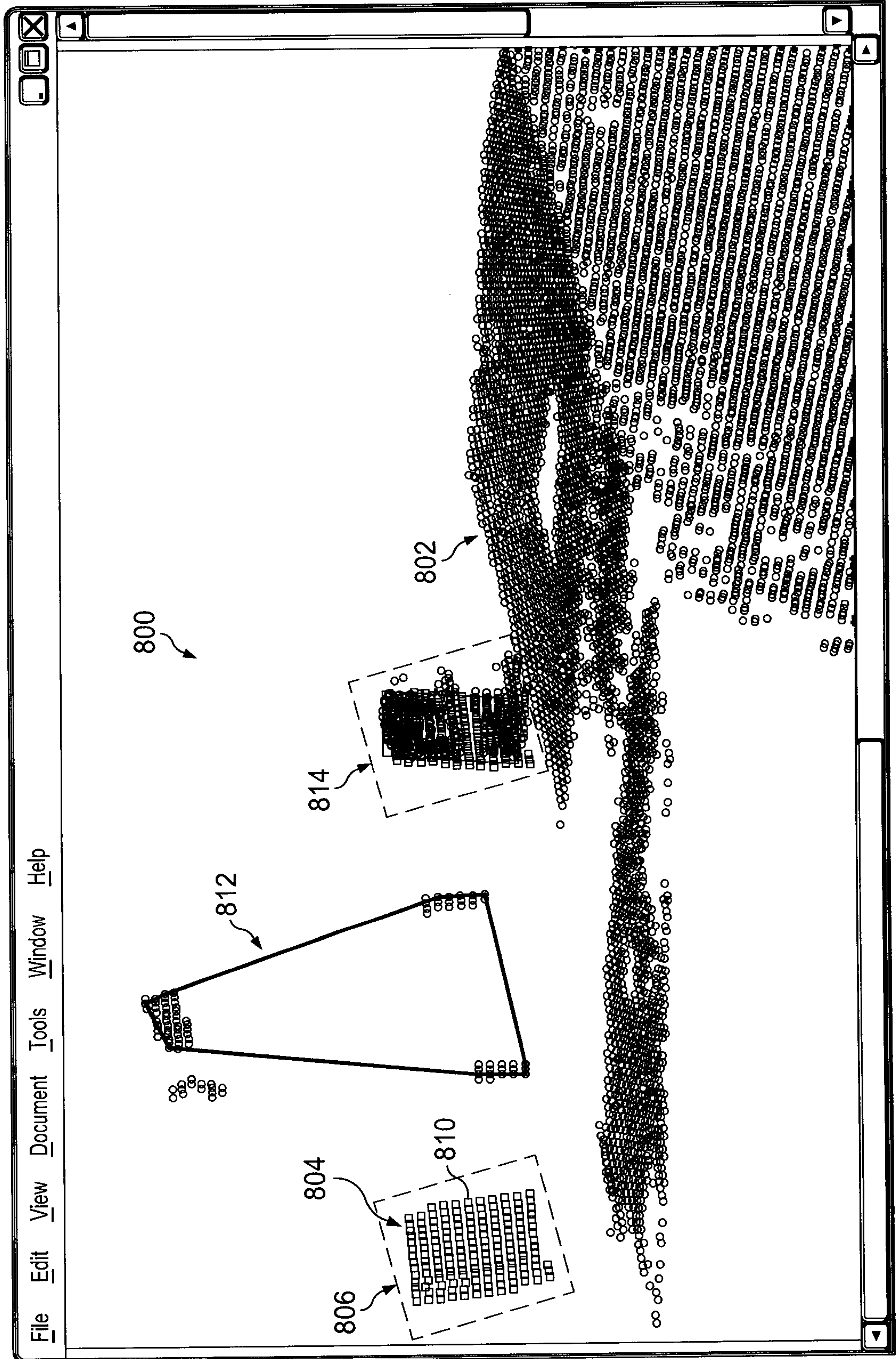


FIG. 8



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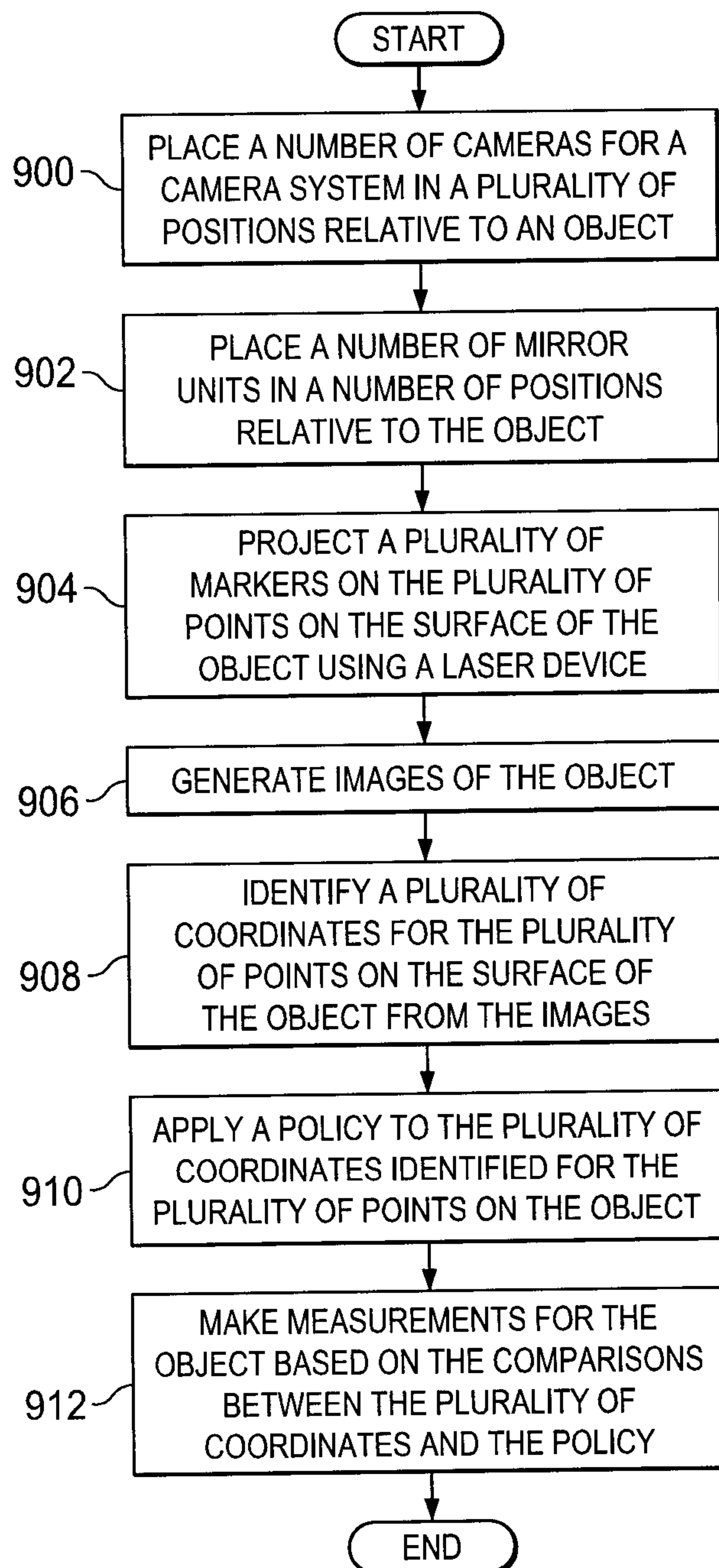


FIG. 9

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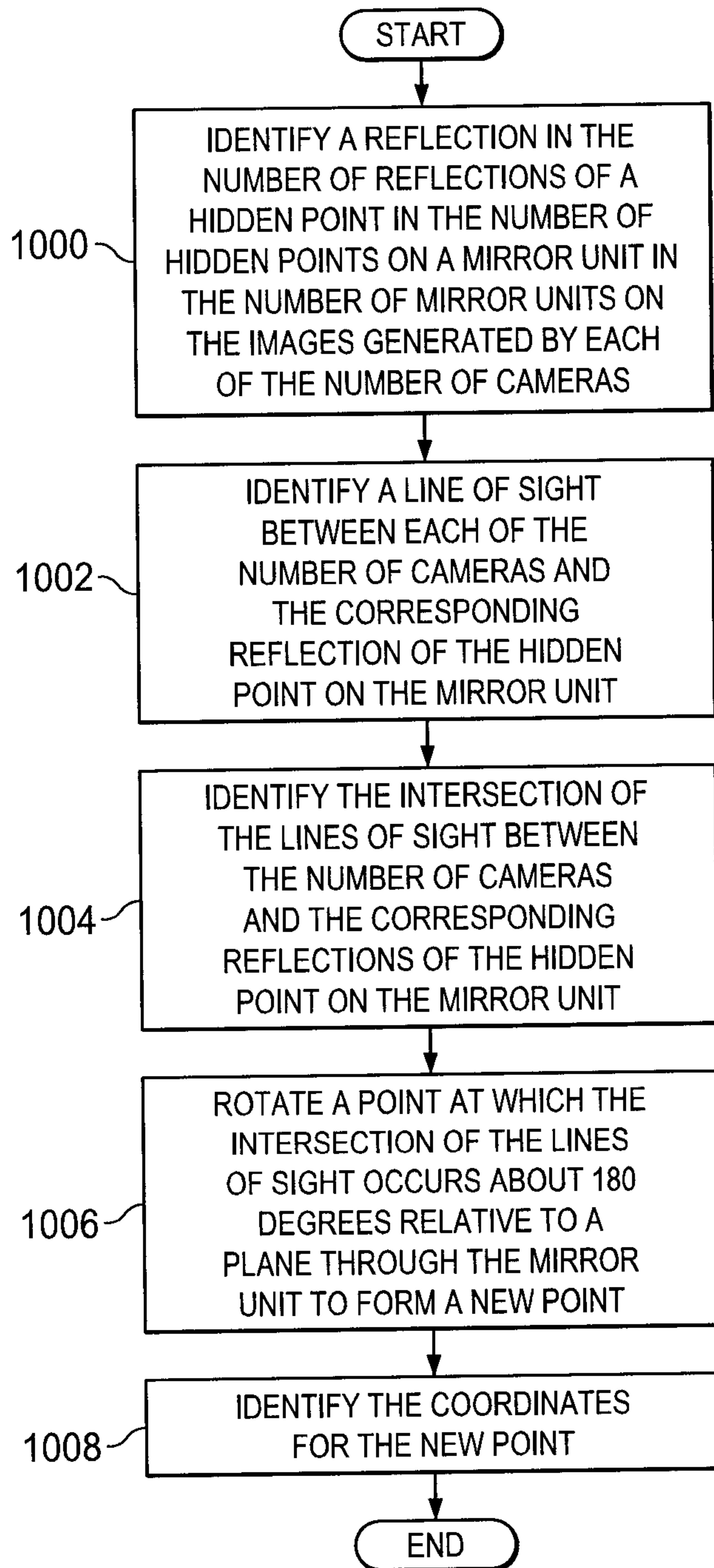


FIG. 10

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FIG. 11

