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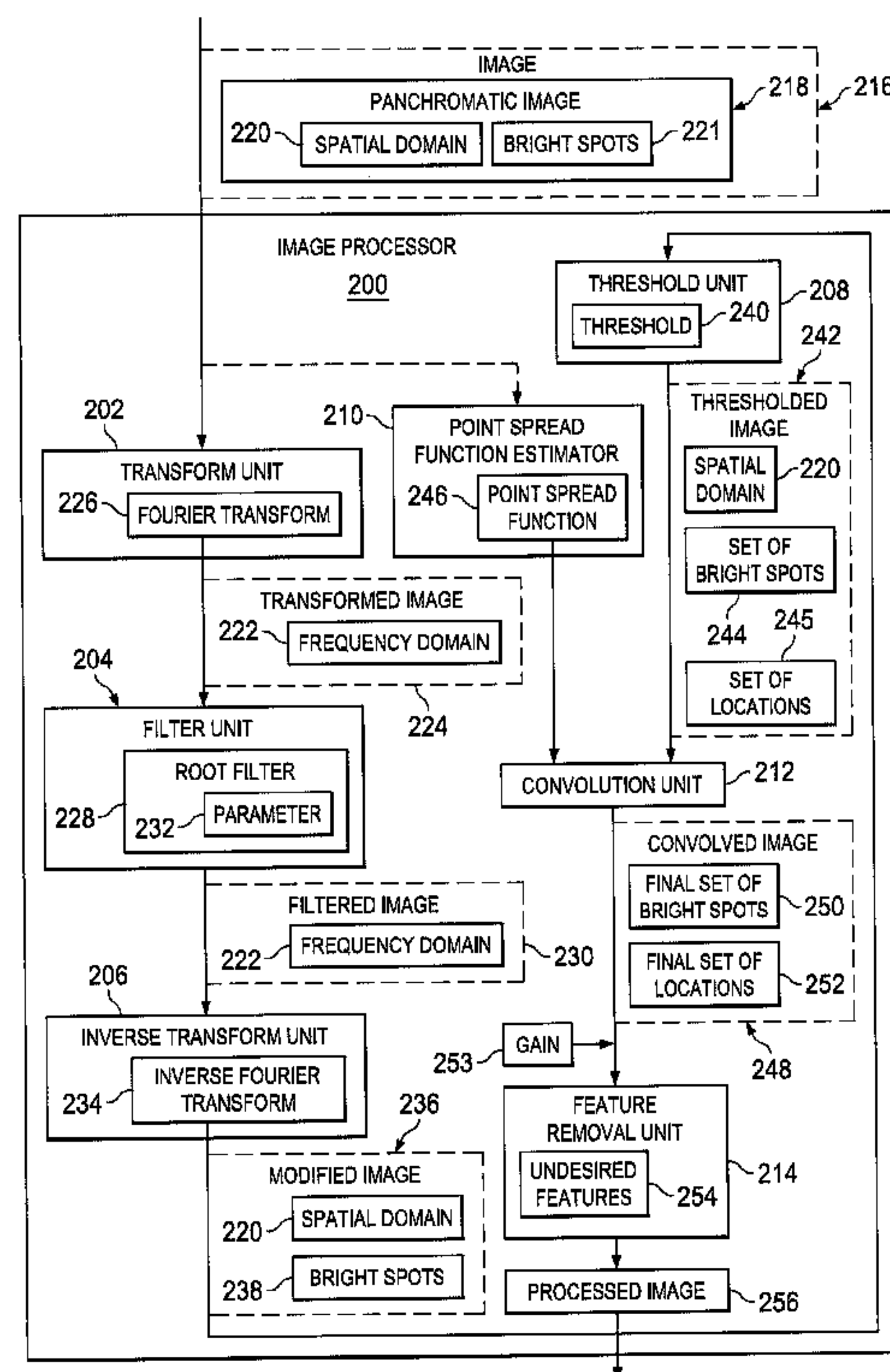
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(54) Titre : SYSTÈME DE SUPPRESSION DE REFLET

(54) Title: REFLECTION REMOVAL SYSTEM



(57) Abrégé/Abstract:

A method and apparatus for removing undesired features in an image. The image is converted from a spatial domain to a frequency domain to form a transformed image. A filter is applied to the transformed image to form a filtered image in the frequency domain. The filtered image is converted from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image. The undesired feature is removed from the image using the modified image to form a processed image.

ABSTRACT

A method and apparatus for removing undesired features in an image. The image is converted from a spatial domain to a frequency domain to form a transformed image. A filter is applied to the transformed image to form a filtered image in the frequency domain. The filtered image is converted from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image. The undesired feature is removed from the image using the modified image to form a processed image.

REFLECTION REMOVAL SYSTEM

BACKGROUND INFORMATION

Field:

The present disclosure relates generally to processing images and, in particular, to removing undesired features from images. Still more particularly, the present disclosure relates to a method and apparatus for removing undesired bright spots in an image.

Background:

In some situations, undesired features may appear in images of scenes generated using a sensor system. For example, reflections of light off of surfaces in a scene may be detected by the sensor system and appear in the image generated for the scene as bright spots. Light may be reflected off of a surface when a ray of light hits the surface. This ray of light may also be referred to as an incident ray of light. Light may be reflected off of surfaces of various types of objects in a scene. These objects may include, for example, without limitation, people, buildings, aircraft, automobiles, leaves, manmade structures, and other suitable types of objects.

Reflections of light off of surfaces may be categorized as diffuse reflections or specular reflections. A diffuse reflection occurs when an incident ray of light is reflected off of a surface in multiple directions.

A specular reflection occurs when an incident ray of light is reflected off of a surface primarily in a single direction. In particular, a specular reflection occurs when the incident ray of light and the reflected ray of light have the same angle relative to an axis perpendicular to the surface. A specular reflection in a scene may appear as a bright spot in an image generated by a sensor system. A bright spot may be an area in the image in which the pixels in that area have intensity values greater than some selected threshold for brightness.

When the specular reflection is caused by light being reflected off of a large area of the surface, this reflection may be referred to as “glare”. When the specular reflection is light reflected off of a small facet of the surface, this reflection may be referred to as a “glint”. A glint may appear as a small feature in the image having a large intensity relative to the portion of the image surrounding the feature. In other words, a glint may appear as a small bright spot in the image. Typically, bright spots in images caused by glints are undesirable features in images.

When these types of undesirable features occur in an image, identifying and/or analyzing characteristics of objects in an image of a scene may be made more difficult than desired. For example, when an image is generated for an object, identification of the object may be more difficult than desired or may take more time than desired when undesired features are present in the image. These undesired features may make it more difficult to identify characteristics of the object that are used to identify the object itself.

As another example, if successive images are taken of the object at different times, those images may be compared to each other to determine whether changes are present in the object. The images may be used to determine whether inconsistencies may have occurred in subsequent images of the object. The presence of undesired features in these images, such as bright spots caused by glints, may make the identification of inconsistencies more difficult and time-consuming than desired.

Some currently available systems for reducing glints in images use high speed mechanical optics attached to imaging systems. These mechanical optics may include, for example, polarizers and optical filters. These types of mechanical optics may reduce the overall transmission of light through an imaging system. Reducing the transmission of light may reduce the amount of information provided in the images generated by the imaging system. Further, these types of mechanical optics may increase the weight and cost of imaging systems more than desired.

Therefore, it would be advantageous to have a method and apparatus that takes into account at least some of the issues discussed above as well as possibly other issues.

SUMMARY

In one advantageous embodiment, a method for removing undesired features in an image is provided. The image is converted from a spatial domain to a frequency domain to form a transformed image. A filter is applied to the transformed image to form a filtered image in the frequency domain. The filtered image is converted from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image. The undesired feature is removed from the image using the modified image to form a processed image.

Other alternative embodiments contemplate identifying characteristics and/or an object in the image using the processed image. Further, the method may include determining whether an inconsistency is present in an object in the image using the processed image. Also, the determining whether the inconsistency is present in the object using the processed image may further include comparing the processed image with another image of the object to form a comparison, and determining whether the inconsistency is present using the comparison.

In another advantageous embodiment, an apparatus comprises a computer system. The computer system is configured to convert an image from a spatial domain to a frequency domain to form a transformed image. The computer system is further configured to apply a filter to the transformed image to form a filtered image in the frequency domain. The computer system is further configured to convert the filtered image from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is

increased as compared to the intensity of the undesired feature in the image. The computer system is further configured to remove the undesired feature from the image using the modified image to form a processed image.

The apparatus may also optionally include a sensor system configured to generate the image of a scene, wherein the undesired feature in the image is a bright spot in the image caused by a glint in the scene. Also contemplated is wherein the apparatus being configured to convert the image from the spatial domain to the frequency domain to form the transformed image, includes the computer system configured to compute a Fourier transform for the image that converts the image from the spatial domain to the transformed image in the frequency domain.

The apparatus in being configured to apply the filter to the transformed image to form the filtered image in the frequency domain, may also have the computer system configured to scale amplitudes for an amplitude component for the Fourier transform of the image without affecting phases in a phase component for the Fourier transform using a root filter to form the filtered image, wherein the root filter scales the amplitudes in a non-linear manner.

Other optional arrangements contemplate that wherein in being configured to remove the undesired feature from the image using the modified image to form the processed image, the computer system is configured to apply a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image; convolve the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a second location for the undesired feature in the image; and subtract the convolved image from the image to form the processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature.

In yet another advantageous embodiment, a vehicle inspection system comprises a sensor system, an image processor, and an image analyzer. The sensor system is configured to generate images of a vehicle. The image processor is configured to receive an image from the sensor system. The image processor is further configured to convert an image from a spatial domain to a frequency domain to form a transformed image. The image processor is further configured to apply a filter to the transformed image to form a filtered image in the frequency domain. The image processor is further configured to convert the filtered image from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image. The image processor is further configured to remove the undesired feature from the image using the modified image to form a processed image. The image analyzer is configured to analyze the processed image to determine whether an inconsistency is present in the vehicle.

Other contemplated vehicle inspection systems may include a display system, wherein the image analyzer is configured to display an indication of whether the inconsistency is present in the vehicle on the display system. Alternatively preferred image analyzers may be further configured to generate a report indicating whether the inconsistency is present in the vehicle.

According to another embodiment, there is provided a method for removing an undesired feature in an image, the method comprising: converting the image from a spatial domain to a frequency domain to form a transformed image; applying a filter to the transformed image to form a filtered image in the frequency domain; converting the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of the undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and removing the undesired feature from the image. Removing the undesired feature comprises: applying a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image; convolving the modified image with a point spread function for the image to

form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a second location for the undesired feature in the image; and subtracting the convolved image from the image to form a processed image, wherein a portion of the image at the second
5 location for the undesired feature in the image is removed from the image to remove the undesired feature.

According to another embodiment, there is provided an apparatus comprising a computer system configured to: convert an image from a spatial domain to a frequency domain to form a transformed image; apply a filter to the transformed
10 image to form a filtered image in the frequency domain; convert the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and remove the undesired feature from the image. In being configured to remove the undesired
15 feature, the computer system is configured to: apply a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image; convolve the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that
20 corresponds to a second location for the undesired feature in the image; and subtract the convolved image from the image to form a processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature.

According to another embodiment, there is provided a vehicle inspection
25 system comprising a sensor system configured to generate images of a vehicle. The vehicle inspection system further comprises an image processor configured to: receive an image from the sensor system; convert the image from a spatial domain to a frequency domain to form a transformed image; apply a filter to the transformed image to form a filtered image in the frequency domain; convert the filtered image
30 from the frequency domain back into the spatial domain to form a modified image,

wherein an intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and remove the undesired feature from the image. In being configured to remove the undesired feature from the image using the modified image, a computer system is configured to:

5 apply a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image; convolve the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a second location for the

10 undesired feature in the image; and subtract the convolved image from the image to form a processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature. The vehicle inspection system further comprises an image analyzer configured to analyze the processed image to determine whether an inconsistency is

15 present in the vehicle.

According to another embodiment, there is provided an apparatus for removing an undesired feature in an image, the apparatus comprising: a means for converting the image from a spatial domain to a frequency domain to form a transformed image; a means for applying a filter to the transformed image to form a filtered image in the

20 frequency domain; a means for converting the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of the undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and a means for removing the undesired feature from the image. The means for removing the undesired feature comprises: a

25 means for applying a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image; a means for convolving the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a

30 second location for the undesired feature in the image; and a means for subtracting

the convolved image from the image to form a processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature.

5 The features, functions, and advantages can 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

10 The novel features believed characteristic of the advantageous embodiments are set forth in the appended claims. The advantageous embodiments, however, as well as a preferred mode of use, further objectives, and advantages thereof will best

be understood by reference to the following detailed description of an advantageous embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an illustration of an image processing environment in the form of a block diagram in accordance with an advantageous embodiment;

Figure 2 is an illustration of an image processor in the form of a block diagram in accordance with an advantageous embodiment;

Figure 3 is an illustration of a panchromatic image in accordance with an advantageous embodiment;

Figure 4 is an illustration of a thresholded image in accordance with an advantageous embodiment;

Figure 5 is an illustration of a processed image in accordance with an advantageous embodiment;

Figure 6 is an illustration of amplitude spectrums in accordance with an advantageous embodiment;

Figure 7 is an illustration of a flowchart of a process for removing undesired features from an image in accordance with an advantageous embodiment;

Figure 8 is an illustration of a flowchart of a process for analyzing an image in accordance with an advantageous embodiment;

Figure 9 is an illustration of a flowchart of a process for analyzing an image in accordance with an advantageous embodiment; and

Figure 10 is an illustration of a data processing system in accordance with an advantageous embodiment.

DETAILED DESCRIPTION

The different advantageous embodiments recognize and take into account one or more considerations. For example, the different advantageous embodiments recognize and take into account that images of a scene may be generated using different wavelengths. In other words, multiple wavelength measurements may be made for objects in the scene. By generating images of the scene using different wavelengths, features that appear in an image in response to reflections in the scene, such as glints, may be identified and removed from the images.

However, the different advantageous embodiments recognize and take into account that some sensors are unable to make these types of wavelength measurements. For example, panchromatic image sensors do not provide this type of information. A panchromatic image sensor may only provide a single band in which the image comprises data in shades of gray.

The different advantageous embodiments also recognize and take into account that filtering may be performed to suppress undesired features in the data for the image. The different advantageous embodiments, however, recognize and take into account that differentiating undesired features caused by glints from other features in the image for objects in the scene may be more difficult and/or time-consuming than desired.

Additionally, the different advantageous embodiments recognize and take into account that currently available systems for reducing glints that use high speed mechanical optics may not allow glints to be removed in images that were previously generated. For example, historical data used in the testing and evaluation of an object may include images from some number of weeks, months, or years prior to a current time. The different advantageous embodiments recognize and take into account that reducing glints in these previously generated images is desirable.

The different advantageous embodiments also recognize and take into account that currently available imaging systems that are configured to reduce glints

may be unable to adapt to changing conditions, such as environmental conditions. For example, with currently available imaging systems equipped with polarizers configured to reduce glints in the images generated by the imaging system, adjusting the polarizers to take into account changing weather conditions, wind conditions, and/or other types of environmental conditions may not be possible. As a result, some portion of the images generated by the imaging system may have more glints than desired.

Further, some currently available systems for reducing glints may use motorized optical filters that adjust the polarization of the lens of an imaging system. The different advantageous embodiments recognize and take into account that these types of systems may be unable to process images being generated at higher frames per second. As a result, processing images in which glints have been reduced in substantially real-time may not be possible with currently available systems.

Thus, the different advantageous embodiments provide a method and apparatus for removing undesired features from an image that are caused by glints. In the different advantageous embodiments, an undesired feature may be a feature that makes analyzing the image more difficult and/or time-consuming than desired.

In one advantageous embodiment, a method for removing undesired features in an image is provided. An image is converted from a spatial domain to a frequency domain to form a transformed image. A filter is applied to the transformed image to form a filtered image in the frequency domain. The filtered image is converted from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image. The undesired feature is removed from the image using the modified image to form a processed image.

This information may then be used for a number of different purposes. For example, the processed image may be used to identify an object in a scene captured in the image, identify inconsistencies in the object, identify characteristics

about the object, and/or perform other suitable operations with respect to the object in the image.

Turning now to **Figure 1**, an illustration of an image processing environment in the form of a block diagram is depicted in accordance with an advantageous embodiment. In these illustrative examples, image processing environment **100** includes scene **102**, sensor system **104**, and computer system **105**. Sensor system **104** may be configured to generate images **106** of scene **102**.

As depicted, sensor system **104** may comprise number of sensors **108**. As used herein, a number of items means one or more items. For example, “a number of sensors” means one or more sensors. In these illustrative examples, number of sensors **108** may take the form of number of imaging sensors **110** configured to detect electromagnetic radiation within band **112**.

Band **112** may be a continuous range of frequencies or a continuous range of wavelengths. When band **112** is within the visible spectrum of electromagnetic radiation, number of imaging sensors **110** generates images **106** of scene **102** in the form of panchromatic images **114**. When band **112** is within other portions of the spectrum of electromagnetic radiation, images **106** may be referred to as broadband images.

In these illustrative examples, images **106** take the form of panchromatic images **114**. Panchromatic images **114** comprise only shades of gray ranging from black to white. In particular, the values for pixels in these types of images contain only intensity information. In other words, the values for pixels in panchromatic images **114** indicate intensity and not color.

As one illustrative example, number of objects **116** may be present in scene **102**. Number of objects **116** in scene **102** may include, for example, without limitation, vehicles, aircraft, automobiles, people, buildings, manmade structures, roads, trees, a grassy patch of land, a surface of an ocean, a lake surface, and other suitable types of objects.

Number of imaging sensors **110** is configured to detect the brightness of number of objects **116** in scene **102** and generate image **118**. Image **118** is a two-dimensional image in these illustrative examples. In particular, number of imaging sensors **110** measures the intensity of light in band **112** detected at number of imaging sensors **110** to generate a value for each pixel in image **118**. The value may be, for example, between about 0 and about 255. In this manner, image **118** is a panchromatic image.

Sensor system **104** sends image **118** to computer system **105** for processing. In these illustrative examples, computer system **105** comprises a number of computers. When more than one computer is present in computer system **105**, those computers may be in communication with each other.

As depicted, image processor **120** and image analyzer **122** are present in computer system **105**. Image processor **120** and image analyzer **122** are modules that may be implemented using hardware, software, or a combination of the two in computer system **105**. In some illustrative embodiments, these modules may be used independently from other components in computer system **105**.

When these modules are implemented as hardware, the modules may be implemented using a number of circuits configured to perform desired functions and/or processes. These number of circuits may include, for example, at least one of an integrated circuit, an application-specific integrated circuit, a programmable logic array, a general logic array, a field programmable gate array, a programmable logic device, a complex programmable logic device, a programmable logic controller, a macrocell array, and other suitable types of circuits.

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 also may include item A, item B, and item C, or item B and item C. In other examples, “at least one of” may be, for example, without

limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; and other suitable combinations.

Further, in these illustrative examples, computer system **105** also includes display system **124**. Display system **124** may comprise one or more display devices. In these illustrative examples, the different components within computer system **105** may be located in the same location or in different locations, depending on the particular implementation.

In some illustrative examples, computer system **105** may be a distributed computer system, such as a network data processing system. In other illustrative examples, computer system **105** may be comprised entirely of hardware circuits in which processes may be implemented in hardware rather than in software.

In these illustrative examples, image processor **120** is configured to receive and process image **118**. In particular, image processor **120** is configured to process image **118** to remove undesired features **126** from image **118**. More specifically, image processor **120** processes image **118** to remove undesired features **126** from image **118** that are caused by undesired reflections **130** in scene **102**. In particular, undesired reflections **130** may be glints **131**.

Glints **131** are specular reflections of light off of surfaces in number of objects **116** in scene **102** that appear in image **118**. A glint may appear in image **118** as a small bright spot in image **118** having a larger intensity as compared to the portion of image **118** surrounding the bright spot. In this manner, undesired features **126** caused by glints **131** in scene **102** take the form of undesired bright spots **128** in image **118**. Image processor **120** may be unable to identify which of the bright spots in image **118** are caused by glints **131** using image **118** in its current form.

For example, image processor **120** may detect bright spot **132** in image **118**. Bright spot **132** may include one pixel, two pixels, or some other suitable number of pixels. However, image processor **120** may be unable to determine whether bright spot **132** is caused by glint **134** in scene **102** and is one of undesired bright spots **128** in image **118**. For example, the intensity of bright spot **132** in image **118** may

not be high enough to determine whether bright spot **132** is caused by glint **134** in scene **102**. As a result, image processor **120** may be unable to determine whether bright spot **132** is one of undesired bright spots **128** or a feature for one of number of objects **116** in scene **102**.

In these illustrative examples, the current form of image **118** is in spatial domain **136**. Spatial domain **136** is the image space for image **118**. In particular, spatial domain **136** may be the two-dimensional space for image **118**. In one illustrative example, spatial domain **136** may be defined using an x,y-coordinate system for image **118**. The x-coordinates for image **118** may be for a horizontal direction for image **118**, while the y-coordinates may be for a vertical direction for image **118**.

Image processor **120** converts image **118** from spatial domain **136** to frequency domain **138** to form transformed image **140**. In particular, image processor **120** may compute Fourier transform (FT) **142** for image **118** to convert image **118** from spatial domain **136** to frequency domain **138** to form transformed image **140**. In these illustrative examples, Fourier transform **142** may be selected from one of a Discrete Fourier transform (DFT) and a Fast Fourier transform (FFT). When spatial domain **136** is a two-dimensional space, Fourier transform **142** also may be a two-dimensional Fourier transform.

In these illustrative examples, transformed image **140** comprises amplitude component **144** and phase component **146**. Amplitude component **144** identifies the amplitudes of Fourier transform **142** for image **118**. These amplitudes may also be referred to as magnitudes. Phase component **146** identifies the phases of Fourier transform **142** for image **118**.

Amplitude component **144** may be represented by, for example, an amplitude spectrum. Phase component **146** may be represented by, for example, a phase spectrum. The amplitude spectrum and the phase spectrum plot the amplitudes and phases, respectively, of Fourier transform **142** with respect to frequency.

In these depicted examples, transformed image **140** has a same number of pixels as image **118**. In particular, transformed image **140** may have the same dimensions in pixels as image **118**.

Each pixel in transformed image **140** represents a different spatial frequency **148** in image **118**. Spatial frequency **148** in image **118** is a rate of change for values of pixels in image **118** relative to neighboring pixels. In particular, spatial frequency **148** is defined as the number of changes in the intensity values for the pixels in image **118** per selected distance **150** in image **118** for a particular portion of image **118**. Selected distance **150** may be in units of, for example, pixels, millimeters, centimeters, or some other suitable unit of distance with respect to transformed image **140**.

In this manner, changes in position in transformed image **140** correspond to changes in spatial frequency **148**. Further, the value for a pixel in transformed image **140** indicates a difference between a lightest gray level and a darkest gray level over selected distance **150** at the particular spatial frequency **148** represented by the pixel. This change from a lightest gray level to a darkest gray level over selected distance **150** is referred to as one period or one cycle.

For example, if a pixel in transformed image **140** representing spatial frequency **148** of 1 cycle every 10 pixels has a value of 20, then the intensity values for the pixels in image **118** over 10 pixels may vary from one of a lightest gray level to a darkest gray level and a darkest gray level to a lightest gray level. Further, the contrast between the lightest gray level and the darkest gray level may be about two times the value for the pixel. In other words, this contrast is about 40 gray levels between the lightest gray level and the darkest gray level.

In these depicted examples, smaller features in image **118** may have higher spatial frequencies as compared to larger features. As a result, smaller features in image **118** may be represented in higher frequency content in transformed image **140** as compared to the larger features in image **118**.

In other words, these smaller features in image **118** may be represented in the pixels for transformed image **140** that correspond to higher spatial frequencies as compared to the larger features in image **118** that may be represented in the pixels for transformed image **140** that correspond to lower spatial frequencies. As one illustrative example, undesired bright spots **128** in image **118** caused by glints **131**, which may be small features in image **118**, may be represented in the high frequency content in transformed image **140**.

In these illustrative examples, image processor **120** applies filter **152** to transformed image **140** to form filtered image **154** in frequency domain **138**. Filter **152** may take the form of, for example, without limitation, a non-linear filter, a linear filter, a high-frequency pass filter, and/or some other suitable type of filter.

In these depicted examples, filter **152** may be configured to change amplitude component **144** for Fourier transform **142** for image **118** without changing phase component **146**. In particular, filter **152** changes the amplitudes for high-frequency content in transformed image **140**.

More specifically, when filter **152** is applied to transformed image **140**, the amplitudes for high-frequency content in transformed image **140** are increased relative to the amplitudes for low-frequency content in transformed image **140**. In other words, the ratio between the amplitudes for high-frequency content and the amplitudes for low-frequency content in filtered image **154** is reduced as compared to the ratio between the amplitudes for high-frequency content and the amplitudes for low-frequency content in transformed image **140**.

In other words, the amplitudes for high-frequency content in transformed image **140** are enhanced in filtered image **154** such that the features in image **118** corresponding to this high frequency content also may be enhanced. In particular, the amplitudes for high frequency content corresponding to undesired bright spots **128** caused by glints **131** in image **118** are enhanced in filtered image **154**.

Thereafter, image processor **120** computes inverse Fourier transform **155** for transformed image **140** to convert transformed image **140** in frequency domain **138**

back into spatial domain **136**. This conversion forms modified image **156**. In particular, the intensities of small features, such as undesired bright spots **128** caused by glints **131**, in modified image **156** may be increased as compared to the intensities of these features in image **118**. In this manner, undesired bright spots **128** caused by glints **131** may be more easily distinguished in modified image **156** from other features as compared to image **118**.

Image processor **120** then uses modified image **156** to remove undesired bright spots **128** caused by glints **131** from modified image **156**. In particular, image processor **120** identifies locations **158** of undesired bright spots **128** in modified image **156** and then reduces and/or removes undesired bright spots **128** from locations **158** in image **118**. In these illustrative examples, the reduction and/or removal of undesired bright spots **128** from modified image **156** forms processed image **160**. In this manner, undesired bright spots **128** caused by glints **131** may be suppressed.

Image processor **120** sends processed image **160** to image analyzer **122** for analysis. Image analyzer **122** may analyze processed image **160** in a number of different ways. For example, image analyzer **122** may identify characteristics **162** for number of objects **116** using processed image **160**. Characteristics **162** for number of objects **116** may include, for example, an inconsistency in an object, edges of an object, dimensions for an object, an identification of an object, and/or other suitable types of characteristics for an object in number of objects **116**.

In some illustrative examples, image processor **120** and image analyzer **122** may be implemented in vehicle inspection system **164**. Vehicle inspection system **164** is configured to determine whether inconsistency **166** is present in object **168** in number of objects **116** using processed image **160**. Object **168** may be a vehicle in these illustrative examples. An inconsistency in object **168** may be a feature or characteristic present in object **168** that is not expected to be present or is undesired in object **168** in these illustrative examples.

Identifying inconsistency **166** may be performed in a number of different ways. For example, processed image **160** may be compared to image **170** stored in database **172**. Image **170** is another image of object **168** generated prior to image **118** of object **168** being generated. This comparison of processed image **160** to image **170** may be used to determine whether inconsistency **166** is present.

In other illustrative examples, image processor **120** and image analyzer **122** may be implemented in object identification system **174**. With this type of implementation, image analyzer **122** may compare image **170** to processed image **160** to generate identification **176** of object **168**. In some cases, processed image **160** may be compared to multiple images present in database **172** to identify object **168**.

In these illustrative examples, vehicle inspection system **164** and/or object identification system **174** may be configured to generate a display on display system **124** using the results of the analysis of processed image **160** performed by image analyzer **122**. In some illustrative examples, image analyzer **122** may display an indication of inconsistency **166** in object **168** on display system **124**.

In other illustrative examples, image analyzer **122** may generate a report containing an indication of whether inconsistency **166** is present in object **168**, an identification of characteristics **162** for object **168**, identification **176** of object **168**, and/or other suitable information. This report may be, for example, displayed on display system **124**, emailed to a client, stored in a database, and/or managed in some other suitable manner.

Further, depending on the implementation, image processor **120** and/or image analyzer **122** may be configured to display images on display system **124**. For example, image processor **120** and/or image analyzer **122** may display any of image **118** and/or processed image **160** on display system **124**.

The illustration of image processing environment **100** in **Figure 1** is not meant to imply physical or architectural limitations to the manner in which an advantageous embodiment may be implemented. Other components in addition to and/or in place

of the ones illustrated may be used. Some components may be unnecessary. 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 an advantageous embodiment.

For example, in some illustrative examples, image analyzer **122** and image processor **120** may be located in different locations. For example, image processor **120** may be located in the same platform as sensor system **104**, while image analyzer **122** may be located in some other platform remote to sensor system **104**. In other illustrative examples, image processor **120** and image analyzer **122** may be implemented in a same module in computer system **105**.

Further, although object **168** is described as a vehicle, object **168** may take a number of different forms. For example, object **168** may be selected from one of a mobile platform, a stationary platform, a land-based structure, an aquatic-based structure, a space-based structure, an aircraft, a surface ship, a tank, a personnel carrier, a train, a spacecraft, a space station, a satellite, a submarine, an automobile, a power plant, a bridge, a dam, a manufacturing facility, a building, a skin panel, an engine, a section of a gas pipeline, and other suitable objects.

With reference now to **Figure 2**, an illustration of an image processor in the form of a block diagram is depicted in accordance with an advantageous embodiment. In this illustrative example, image processor **200** is an example of one implementation for image processor **120** in **Figure 1**. As depicted, image processor **200** includes transform unit **202**, filter unit **204**, inverse transform unit **206**, threshold unit **208**, point spread function estimator **210**, convolution unit **212**, and feature removal unit **214**.

In this illustrative example, transform unit **202** receives image **216** from a sensor system, such as sensor system **104** in **Figure 1**. Image **216** takes the form of panchromatic image **218** in this example. Further, image **216** is in spatial domain **220**. Spatial domain **220** is a two-dimensional image space for image **216**. In this

depicted example, image **216** in spatial domain **220** may be represented by the function, $H(x,y)$.

The function, $H(x,y)$, for image **216** is a function for the values of the pixels in image **216** with respect to the x,y locations of the pixels in image **216**. The pixels in image **216** may be arranged in rows and columns. In these illustrative examples, the x location of a pixel identifies a particular row, while the y location of the pixel identifies a particular column.

Bright spots **221** appear in image **216**. Bright spots **221** are small features in image **216** having large intensities relative to the portions of image **216** surrounding bright spots **221**. At least a portion of bright spots **221** may not have intensities large enough to distinguish between bright spots resulting from glints in the scene captured by image **216** and bright spots that are features of the objects in the scene. Image processor **200** is configured to process image **216** to make this distinction.

As depicted, transform unit **202** is configured to convert image **216** from spatial domain **220** to frequency domain **222** to form transformed image **224**. In particular, transform unit **202** computes Fourier transform (FT) **226** for image **216** to form transformed image **224**. Fourier transform **226** for image **216** may be represented by the function, $H(u,v)$. The function, $H(u,v)$, for image **216** is the function, $H(x,y)$, for image **216** converted into frequency domain **222**.

In this illustrative example, filter unit **204** receives transformed image **224** in frequency domain **222** from transform unit **202**. Filter unit **204** applies root filter **228** to transformed image **224** to generate filtered image **230**. In this depicted example, root filter **228** is a non-linear filter that uses parameter **232**, α , to change the amplitude component for Fourier transform **226** for image **216** without changing the phase component for Fourier transform **226**.

In particular, parameter **232**, α , may be an exponent having a value between 0 and 1. Root filter **228** may raise the amplitude component of Fourier transform **226** to the power of parameter **232**. This operation may be equivalent to taking the α^{th}

root of the amplitude component of Fourier transform **226**. In other words, filtered image **230** may be represented by the following equation:

$$F(u,v) = |H(u,v)|^\alpha e^{j\theta(u,v)}. \quad (1)$$

where $F(u,v)$ represents filtered image **230**, $|H(u,v)|$ is the amplitude component for Fourier transform **226** for

image **216**, u is a horizontal component for frequencies in frequency domain **222**, v is a vertical component for frequencies in frequency domain **222**, α is parameter **232** between 0 and 1, e is the exponential function, θ is a phase angle, and j is the square root of -1.

The value of parameter **232**, α , may be selected such that amplitudes of the high frequency content in transformed image **224** are increased relative to the amplitudes of the low frequency content. In particular, the amplitudes of the high frequency content in transformed image **224** may be increased more than the amplitudes of the low frequency content in transformed image **224**. In some cases, the amplitudes of the high frequency content may be decreased to a lesser extent than the amplitudes of the low frequency content in transformed image **224**.

Filtered image **230** generated by filter unit **204** is sent to inverse transform unit **206**. Inverse transform unit **206** computes inverse Fourier transform **234** for filtered image **230** in frequency domain **222** to convert filtered image **230** from frequency domain **222** back into spatial domain **220** in the form of modified image **236**.

In this illustrative example, bright spots **238** appear in modified image **236**. Bright spots **238** may be substantially the same as bright spots **221** in image **216**. Bright spots **238** in modified image **236** in spatial domain **220** may have increased intensities as compared to bright spots **221** in image **216**. In particular, bright spots **238** may have intensities that may allow bright spots resulting from glints in the scene captured by image **216** to be distinguished between bright spots that are features of the objects in the scene.

As depicted, threshold unit **208** receives modified image **236** from inverse transform unit **206**. Threshold unit **208** is configured to apply threshold **240**, K_T , to modified image **236**. In particular, when threshold **240** is applied to modified image **236**, pixels in modified image **236** having a value equal to or less than threshold **240**, K_T , are set to have an amplitude of about zero or some minimum value, while pixels in modified image **236** having a value greater than threshold **240**, K_T , are left unchanged to form thresholded image **242** in spatial domain **220**.

Threshold **240** is selected such that any bright spots **238** that may be caused by glints in the scene captured in image **216** may be identified. For example, pixels in modified image **236** having a value greater than threshold **240**, K_T , may be pixels for set of bright spots **244** in bright spots **238**. As used herein, a set of items means zero or more items. For example, a set of items may be a null or empty set in some cases. In particular, set of bright spots **244** includes the bright spots from bright spots **238** that may be caused by glints in the scene captured in image **216**. In some illustrative examples, set of bright spots **244** may be referred to as a set of glint points.

Set of bright spots **244** may be in set of locations **245** in thresholded image **242**. In this depicted example, parameter **232** may be selected such that a bright spot in set of bright spots **244** may have a width of about one pixel. In particular, parameter **232** is selected such that the smallest bright spots in set of bright spots **244** may occupy about one pixel or less. Further, in some illustrative examples, threshold unit **208** may be configured to apply more than one threshold to modified image **236**.

Convolution unit **212** is configured to convolve thresholded image **242** with point spread function **246** for image **216** to generate convolved image **248** in spatial domain **220**. In this illustrative example, point spread function **246** may be generated by point spread function estimator **210**. Point spread function **246** describes the response of the sensor system that generated image **216** to a point source or point object.

For example, a point feature in scene **102** of **Figure 1** may be a feature for an object in the scene that may occupy about one pixel in image **216** based on, for example, a distance between the sensor system and the object. However, the sensor system that generates image **216** may cause this point feature to be blurred in image **216** such that the point feature occupies more than one pixel. Point spread function **246** describes this blurring of the point feature. In other words, point spread function **246** describes the blurring of point features by the system that generated image **216**. In these illustrative examples, point spread function **246** may take the form of a Gaussian function, $p(x,y)$.

In one illustrative example, point spread function estimator **210** estimates point spread function **246** using image **216**. In other illustrative examples, point spread function estimator **210** may obtain point spread function **246** from user input, a database, or some other suitable source. For example, parameters for the sensor system that generated image **216** may be well-known, and point spread function **246** may already be defined for the sensor system.

In this illustrative example, convolution unit **212** convolves point spread function **246** with thresholded image **242** to generate convolved image **248** that estimates set of locations **245** for set of bright posts **244** to form final set of locations **252** for final set of bright spots **250**. Final set of bright spots **250** in final set of locations **252** estimates the contribution of glints to image **216**.

In particular, final set of locations **252** take into account the blurring effect of the sensor system. In other words, final set of locations **252** may be the locations that correspond to the locations of the corresponding bright points in bright spots **221** in image **216**. The convolution of the estimated point spread function **246** and a function for thresholded image **242** in spatial domain **220** may be the integral of the product of these two functions after one is reversed and shifted.

As depicted, feature removal unit **214** is configured to receive convolved image **248**. In some illustrative examples, gain **253** may be applied to convolved image **248** prior to convolved image **248** being received by feature removal unit **214**.

In these illustrative examples, gain **253** may be selected to account for the particular type of sensor system that generated image **216**, interactions between glints in the scene that may affect the bright spots in image **216**, and/or other suitable factors.

Feature removal unit **214** subtracts convolved image **248** from image **216**. In other words, the portions of image **216** in locations in image **216** corresponding to final set of locations **252** of final set of bright spots **250** in convolved image **248** are removed from image **216** to form processed image **256**. This removal is the removal of undesired features **254** from image **216**. In particular, this removal is the removal of undesired features **254** caused by glints in the scene captured in image **216**.

In this illustrative example, the removal of undesired features **254** may be performed by setting pixel values in the portions of image **216** in locations corresponding to final set of locations **252** of final set of bright spots **250** to zero or some minimum value other than zero. A minimum value other than zero may be selected to take into account that a bright spot in bright spots **221** in image **216** may be caused by other reflections in addition to glints. For example, the bright spot also may be caused by a diffused reflection.

Image processor **200** may send processed image **256** to an image analyzer, such as image analyzer **122** in **Figure 1**. In this manner, analysis may be performed on processed image **256** in which undesired features **254** have been removed instead of image **216** in which undesired features **254** may still be present. The analysis of processed image **256** may be more accurate as compared to the analysis of image **216**.

The illustration of image processor **200** in **Figure 2** is not to imply physical or architectural limitations to the manner in which an advantageous embodiment may be implemented. In these illustrative examples, image processor **200** may be implemented using other types of components in addition to and/or in place of the ones illustrated. Further, some components illustrated may be combined with other components, or functions may be further separated into additional components.

For example, threshold unit **208** may be implemented as part of feature removal unit **214**. In some illustrative examples, a conversion unit may implement the functions performed by both transform unit **202** and inverse transform unit **206**.

With reference now to **Figure 3**, an illustration of a panchromatic image is depicted in accordance with an advantageous embodiment. Panchromatic image **300** is an example of one of images **106** in **Figure 1** and panchromatic image **218** in **Figure 2**. Panchromatic image **300** is an image of a section of an aircraft fuselage. Panchromatic image **300** is an image in gray scale. As depicted, bright spots **302** are present in panchromatic image **300**. At least a portion of bright spots **302** may be caused by glints in the scene captured in panchromatic image **300**. Bright spot **304** is an example of one of bright spots **302** that is at least partially caused by a glint. Bright spot **304** is in location **306** in panchromatic image **300**.

With reference now to **Figure 4**, an illustration of a thresholded image is depicted in accordance with an advantageous embodiment. Thresholded image **400** is an example of one implementation for thresholded image **242** in **Figure 2**. In particular, thresholded image **400** is an example of the image produced by threshold unit **208** in **Figure 2** after processing of panchromatic image **300** in **Figure 3** by image processor **200** in **Figure 2**.

As depicted, thresholded image **400** is a black and white image comprising pixels **402** having zero values and pixels **404** having non-zero values. Pixels **404** having non-zero values identify locations in thresholded image **400** that correspond to the locations of the portion of bright spots **302** in panchromatic image **300** in **Figure 3** caused by glints.

With reference now to **Figure 5**, an illustration of a processed image is depicted in accordance with an advantageous embodiment. Processed image **500** is an example of one implementation for processed image **256** in **Figure 2**. In particular, processed image **500** is an example of the image generated by image processor **200** in **Figure 2** after panchromatic image **300** from **Figure 3** has been processed to remove undesired features from panchromatic image **300**. These

undesired features are the portion of bright spots **302** in panchromatic image **300** in **Figure 3** caused by glints.

In particular, thresholded image **400** from **Figure 4** may be convolved with the point spread function for panchromatic image **300** to form a convolved image. This convolution may be performed by convolution unit **212** in image processor **200** from **Figure 2**. Feature removal unit **214** in image processor **200** in **Figure 2** may subtract the convolved image from panchromatic image **300** to generate processed image **500**. As depicted, processed image **500** is an image in gray scale.

In this illustrative example, location **502** in processed image **500** corresponds to location **306** in panchromatic image **300**. As depicted in processed image **500**, the effects of glints off of the section of aircraft fuselage in processed image **500** have been substantially removed in location **502**. In particular, the effects of glints have been substantially removed in location **502** as compared to location **306** in panchromatic image **300**. Any brightness remaining in location **502** may be the effects of diffuse reflections off of the section of the aircraft fuselage.

With reference now to **Figure 6**, an illustration of amplitude spectrums is depicted in accordance with an advantageous embodiment. In this illustrative example, plot **600** has horizontal axis **602** and vertical axis **604**. Horizontal axis **602** is spatial frequency in cycles per sample. Vertical axis **604** is amplitude. As depicted, plot **600** includes amplitude spectrum **606** and amplitude spectrum **608**.

Amplitude spectrum **606** is an example of one representation for the amplitude component of a transformed image, such as transformed image **224** in **Figure 2**. Amplitude spectrum **608** is an example of one representation of the amplitude component in a filtered image, such as filtered image **230** in **Figure 2**. The filtered image is the result of applying root filter **228** in **Figure 2** to transformed image **224**.

As illustrated, amplitude spectrum **606** and amplitude spectrum **608** indicate that the ratio of the amplitudes for the higher-frequency content to the amplitudes of the lower-frequency content is reduced in filtered image **230** as compared to the

ratio of the amplitudes for the higher-frequency content to the amplitudes of the lower-frequency content in transformed image **224**. In other words, when root filter **228** is applied to transformed image **224**, the amplitudes of the higher-frequency content are increased relative to the amplitudes of the lower-frequency content. In this illustrative example, the amplitudes for all frequencies in transformed image **224** are decreased when root filter **228** is applied.

With reference now to **Figure 7**, an illustration of a flowchart of a process for removing undesired features from an image is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 7** may be implemented in image processing environment **100** in **Figure 1**. In particular, one or more of the different advantageous embodiments may be implemented in image processor **120** in **Figure 1**. Additionally, image analyzer **122** in **Figure 1** also may be used to implement some operations, depending on the particular implementation.

The process begins by receiving an image of a scene generated by a sensor system (operation **700**). In this illustrative example, the sensor system comprises a number of panchromatic image sensors that generate the image as a panchromatic image. The image of the scene is generated in the spatial domain in this example.

Next, the process converts the image from the spatial domain to a frequency domain to form a transformed image (operation **702**). In particular, in operation **702**, the process computes a Fourier transform for the image that converts the image in the spatial domain to the transformed image in the frequency domain. The Fourier transform for the image comprises an amplitude component and a phase component. Further, in this illustrative example, the Fourier transform may be a Discrete Fourier transform (DFT) or a Fast Fourier transform (FFT).

Then, the process applies a filter to the transformed image to form a filtered image in the frequency domain (operation **704**). In this illustrative example, the filter in operation **704** is a root filter. In particular, the root filter scales amplitudes for the amplitude component of the Fourier transform without changing phases for the phase component of the Fourier transform. The root filter may be configured to

scale the amplitudes for the amplitude component of the Fourier transform in a non-linear manner.

Thereafter, the process converts the filtered image from the frequency domain back into the spatial domain to form a modified image (operation **706**). In operation **706**, an inverse Fourier transform is computed for the filtered image to convert the filtered image in the frequency domain to the modified image in the spatial domain. Intensities of any undesired features in the modified image caused by glints in the scene may be increased as compared to the intensities of undesired features in the image of the scene. In other words, the intensities of any undesired features in the modified image may be enhanced relative to other portions of the image as compared to the intensities of the undesired features in the image generated by the sensor system.

The process then applies a threshold to the modified image to form a thresholded image (operation **708**). In operation **708**, pixels in the modified image having values greater than the threshold are retained to form the thresholded image. Any pixels that are retained contain the undesired features caused by glints in the scene detected by the sensor system. In particular, the modified image may contain a set of bright spots. This set of bright spots corresponds to the small features that appear in the image generated by the sensor system as a result of glints in the scene.

Next, the process convolves the modified image with a point spread function for the image to form a convolved image (operation **710**). The convolved image indicates a set of locations for the set of bright spots identified in the modified image. The set of locations takes into account any blurring effects that may be generated by the sensor system.

Then, the process subtracts the convolved image from the image generated by the sensor system to remove any undesired features caused by glints to form a processed image (operation **712**), with the process terminating thereafter. In operation **712**, subtracting the convolved image from the image generated by the

sensor system removes any portions of the image at locations corresponding to the set of locations for the set of bright spots in the modified image.

With reference now to **Figure 8**, an illustration of a flowchart of a process for analyzing an image is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 8** may be implemented in image processing environment **100** in **Figure 1**. In particular, this process may be implemented in image analyzer **122** in **Figure 1**.

The process begins by receiving a processed image (operation **800**). This processed image may be an image generated by image processor **120** in **Figure 1** using the operations described in **Figure 7**. In particular, this processed image may be the processed image formed in operation **712** in **Figure 7**.

The process analyzes the processed image to generate a result (operation **802**). A determination is made as to whether the result indicates that an inconsistency is present in an object in the image (operation **804**). If an inconsistency is present in the object, the process generates an indication of the presence of the inconsistency (operation **806**), with the process terminating thereafter. The indication may be presented on a display device, sent in an email, stored in a database, or processed in some other suitable manner.

With reference again to operation **804**, if an inconsistency is not present in the object, the process then generates an indication of an absence of an inconsistency (operation **808**), with the process terminating thereafter.

The analysis performed in operation **802** may be performed in a number of different ways. For example, the analysis may be performed directly on the processed image. The data in the processed image may be compared to other images of the object taken at previous times. This comparison may be used to determine whether changes in the object have occurred. These changes may be used to determine whether an inconsistency is present in the object. In these illustrative examples, an inconsistency may be an undesired change in the object.

With reference now to **Figure 9**, an illustration of a flowchart of a process for analyzing an image is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 9** may be implemented in image processing environment **100** in **Figure 1**. In particular, this process may be implemented in image analyzer **122** in **Figure 1**.

The process begins by receiving a processed image (operation **900**). This processed image may be an image generated by image processor **120** using the operations described in **Figure 7**. In particular, this processed image may be the processed image formed in operation **712** in **Figure 7**.

The process then analyzes the processed image to identify an object in the image (operation **902**). This analysis may be made in a number of different ways. For example, a database of prior images or other data may be used as a comparison to the data in the processed image. Based on this comparison, an identification of the object may be made. This identification may identify a particular object or may indicate that the object in the image is unknown.

The process then generates an indication of the identification of the object (operation **904**), with the process terminating thereafter. The indication may be, for example, a report identifying the object.

Turning now to **Figure 10**, an illustration of a data processing system is depicted in accordance with an advantageous embodiment. Data processing system **1000** may be used to implement one or more computers in computer system **105** in **Figure 1** in these depicted examples. In this illustrative example, data processing system **1000** includes communications framework **1002**, which provides communications between processor unit **1004**, memory **1006**, persistent storage **1008**, communications unit **1010**, input/output (I/O) unit **1012**, and display **1014**.

Processor unit **1004** serves to execute instructions for software that may be loaded into memory **1006**. Processor unit **1004** 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, processor unit **1004** may be implemented using a number of heterogeneous processor systems in which a main processor is present with secondary processors on a single chip. As another illustrative example, processor unit **1004** may be a symmetric multi-processor system containing multiple processors of the same type.

Memory **1006** and persistent storage **1008** are examples of storage devices **1016**. 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. Storage devices **1016** may also be referred to as computer readable storage devices in these examples. Memory **1006**, in these examples, may be, for example, a random access memory or any other suitable volatile or non-volatile storage device. Persistent storage **1008** may take various forms, depending on the particular implementation.

For example, persistent storage **1008** may contain one or more components or devices. For example, persistent storage **1008** 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 persistent storage **1008** also may be removable. For example, a removable hard drive may be used for persistent storage **1008**.

Communications unit **1010**, in these examples, provides for communications with other data processing systems or devices. In these examples, communications unit **1010** is a network interface card. Communications unit **1010** may provide communications through the use of either or both physical and wireless communications links.

Input/output unit **1012** allows for input and output of data with other devices that may be connected to data processing system **1000**. For example, input/output unit **1012** may provide a connection for user input through a keyboard, a mouse, and/or some other suitable input device. Further, input/output unit **1012** may send

output to a printer. Display **1014** provides a mechanism to display information to a user.

Instructions for the operating system, applications, and/or programs may be located in storage devices **1016**, which are in communication with processor unit **1004** through communications framework **1002**. In these illustrative examples, the instructions are in a functional form on persistent storage **1008**. These instructions may be loaded into memory **1006** for execution by processor unit **1004**. The processes of the different embodiments may be performed by processor unit **1004** using computer-implemented instructions, which may be located in a memory, such as memory **1006**.

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 processor unit **1004**. The program code in the different embodiments may be embodied on different physical or computer readable storage media, such as memory **1006** or persistent storage **1008**.

Program code **1018** is located in a functional form on computer readable media **1020** that is selectively removable and may be loaded onto or transferred to data processing system **1000** for execution by processor unit **1004**. Program code **1018** and computer readable media **1020** form computer program product **1022** in these examples. In one example, computer readable media **1020** may be computer readable storage media **1024** or computer readable signal media **1026**.

Computer readable storage media **1024** may include, for example, an optical or magnetic disk that is inserted or placed into a drive or other device that is part of persistent storage **1008** for transfer onto a storage device, such as a hard drive, that is part of persistent storage **1008**. Computer readable storage media **1024** also may take the form of a persistent storage, such as a hard drive, a thumb drive, or a flash memory, that is connected to data processing system **1000**. In some instances, computer readable storage media **1024** may not be removable from data processing system **1000**.

In these examples, computer readable storage media **1024** is a physical or tangible storage device used to store program code **1018** rather than a medium that propagates or transmits program code **1018**. Computer readable storage media **1024** is also referred to as a computer readable tangible storage device or a computer readable physical storage device. In other words, computer readable storage media **1024** is a media that can be touched by a person.

Alternatively, program code **1018** may be transferred to data processing system **1000** using computer readable signal media **1026**. Computer readable signal media **1026** may be, for example, a propagated data signal containing program code **1018**. For example, computer readable signal media **1026** 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. In other words, the communications link and/or the connection may be physical or wireless in the illustrative examples.

In some advantageous embodiments, program code **1018** may be downloaded over a network to persistent storage **1008** from another device or data processing system through computer readable signal media **1026** for use within data processing system **1000**. For instance, program code stored in a computer readable storage medium in a server data processing system may be downloaded over a network from the server to data processing system **1000**. The data processing system providing program code **1018** may be a server computer, a client computer, or some other device capable of storing and transmitting program code **1018**.

The different components illustrated for data processing system **1000** are not meant to provide architectural limitations to the manner in which different 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 data processing system **1000**. Other components shown in **Figure 10** 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, processor unit **1004** 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 processor unit **1004** takes the form of a hardware unit, processor unit **1004** 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, a field programmable logic array, a field programmable gate array, and other suitable hardware devices. With this type of implementation, program code **1018** may be omitted, because the processes for the different embodiments are implemented in a hardware unit.

In still another illustrative example, processor unit **1004** may be implemented using a combination of processors found in computers and hardware units. Processor unit **1004** may have a number of hardware units and a number of processors that are configured to run program code **1018**. 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.

In another example, a bus system may be used to implement communications framework **1002** 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.

Additionally, a communications unit may include a number of devices that transmit data, receive data, or transmit and receive data. A communications unit may be, for example, a modem or a network adapter, two network adapters, or some combination thereof. Further, a memory may be, for example, memory **1006**, or a cache, such as found in an interface and memory controller hub that may be present in communications framework **1002**.

Thus, the different advantageous embodiments provide a method and apparatus for removing undesired features caused by glints from an image. In the different advantageous embodiments, an undesired feature may be a feature that makes analyzing the image more difficult and/or time-consuming than desired.

In one advantageous embodiment, a method for removing undesired features in an image is provided. An image is converted from a spatial domain to a frequency domain to form a transformed image. A filter is applied to the transformed image to form a filtered image in the frequency domain. The filtered image is converted from the frequency domain back into the spatial domain to form a modified image. An intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image. The undesired feature is removed from the image using the modified image to form a processed image.

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 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 embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the 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.

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

1. A method for removing an undesired feature in an image, the method comprising:

5 converting the image from a spatial domain to a frequency domain to form a transformed image;

 applying a filter to the transformed image to form a filtered image in the frequency domain;

10 converting the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of the undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and

 removing the undesired feature from the image, wherein removing the undesired feature comprises:

15 applying a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image;

20 convolving the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a second location for the undesired feature in the image; and

 subtracting the convolved image from the image to form a processed image, wherein a portion of the image at the second

location for the undesired feature in the image is removed from the image to remove the undesired feature.

2. The method of claim 1, wherein the image is of a scene and wherein the undesired feature in the image is a bright spot caused by a glint in the scene.

5 3. The method of claim 1 or 2, wherein converting the image from the spatial domain to the frequency domain to form the transformed image comprises:

computing a Fourier transform for the image that converts the image from the spatial domain to the transformed image in the frequency domain.

10 4. The method of claim 3, wherein applying the filter to the transformed image to form the filtered image in the frequency domain comprises:

changing an amplitude component for the Fourier transform of the image without changing a phase component for the Fourier transform of the image to form the filtered image.

15 5. The method of claim 4, wherein changing the amplitude component for the Fourier transform of the image without changing the phase component for the Fourier transform of the image to form the filtered image comprises:

20 scaling amplitudes for the amplitude component for the Fourier transform of the image without affecting phases in the phase component for the Fourier transform using a root filter to form the filtered image, wherein the root filter scales the amplitudes in a non-linear manner.

- 6.** The method of any one of claims **1** to **5**, wherein converting the filtered image from the frequency domain back into the spatial domain to form the modified image comprises:

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computing an inverse Fourier transform for the filtered image that converts the filtered image from the frequency domain to the spatial domain, wherein the intensity of the undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image.

- 7.** The method of any one of claims **1** to **6** further comprising:

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identifying characteristics of an object in the image using the processed image.

- 8.** The method of any one of claims **1** to **6** further comprising:

identifying an object in the image using the processed image.

- 9.** The method of any one of claims **1** to **6** further comprising:

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determining whether an inconsistency is present in an object in the image using the processed image.

- 10.** The method of claim **9**, wherein determining whether the inconsistency is present in the object using the processed image comprises:

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comparing the processed image with another image of the object to form a comparison; and

determining whether the inconsistency is present using the comparison.

11. At least one computer-readable medium comprising codes stored thereon that, when executed by at least one computer, cause the at least one computer to implement the method of any one of claims **1** to **10**.

12. An apparatus comprising:

5 a computer system configured to:

convert an image from a spatial domain to a frequency domain to form a transformed image;

apply a filter to the transformed image to form a filtered image in the frequency domain;

10 convert the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and

15 remove the undesired feature from the image,

wherein in being configured to remove the undesired feature, the computer system is configured to:

20 apply a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image;

convolve the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the

convolved image that corresponds to a second location for the undesired feature in the image; and

subtract the convolved image from the image to form a processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature.

13. The apparatus of claim **12** further comprising:

a sensor system configured to generate the image of a scene, wherein the undesired feature in the image is a bright spot in the image caused by a glint in the scene.

14. The apparatus of claim **12** or **13**, wherein in being configured to convert the image from the spatial domain to the frequency domain to form the transformed image, the computer system is configured to compute a Fourier transform for the image that converts the image from the spatial domain to the transformed image in the frequency domain.

15. The apparatus of claim **14**, wherein in being configured to apply the filter to the transformed image to form the filtered image in the frequency domain, the computer system is configured to scale amplitudes for an amplitude component for the Fourier transform of the image without affecting phases in a phase component for the Fourier transform using a root filter to form the filtered image, wherein the root filter scales the amplitudes in a non-linear manner.

16. A vehicle inspection system comprising:

a sensor system configured to generate images of a vehicle;

an image processor configured to:

receive an image from the sensor system;

convert the image from a spatial domain to a frequency domain to form a transformed image;

5 apply a filter to the transformed image to form a filtered image in the frequency domain;

10 convert the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of an undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and

remove the undesired feature from the image,

wherein in being configured to remove the undesired feature from the image using the modified image, a computer system is configured to:

15 apply a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image;

20 convolve the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a second location for the undesired feature in the image; and

subtract the convolved image from the image to form a processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature; and

5 an image analyzer configured to analyze the processed image to determine whether an inconsistency is present in the vehicle.

17. The vehicle inspection system of claim **16**, wherein in being configured to analyze the processed image to determine whether the inconsistency is present, the image analyzer is configured to

10 compare the processed image with another image of the vehicle to form a comparison; and

 determine whether the inconsistency is present using the comparison.

18. The vehicle inspection system of claim **16** or **17** further comprising:

15 a display system, wherein the image analyzer is configured to display an indication of whether the inconsistency is present in the vehicle on the display system.

19. The vehicle inspection system of claim **16**, **17**, or **18**, wherein the image analyzer is further configured to generate a report indicating whether the inconsistency is present in the vehicle.

20 **20.** An apparatus for removing an undesired feature in an image, the apparatus comprising:

 a means for converting the image from a spatial domain to a frequency domain to form a transformed image;

a means for applying a filter to the transformed image to form a filtered image in the frequency domain;

5 a means for converting the filtered image from the frequency domain back into the spatial domain to form a modified image, wherein an intensity of the undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image; and

a means for removing the undesired feature from the image, wherein the means for removing the undesired feature comprises:

10 a means for applying a threshold to the modified image in which pixels in the modified image having values greater than the threshold are retained to form a thresholded image;

15 a means for convolving the modified image with a point spread function for the image to form a convolved image, wherein the convolved image indicates a first location for the undesired feature in the convolved image that corresponds to a second location for the undesired feature in the image; and

20 a means for subtracting the convolved image from the image to form a processed image, wherein a portion of the image at the second location for the undesired feature in the image is removed from the image to remove the undesired feature.

21. The apparatus of claim **20**, wherein the means for converting the image from the spatial domain to the frequency domain to form the transformed image comprises:

5 a means for computing a Fourier transform for the image that converts the image from the spatial domain to the transformed image in the frequency domain.

22. The apparatus of claim **21**, wherein the means for applying the filter to the transformed image to form the filtered image in the frequency domain comprises:

10 a means for changing an amplitude component for the Fourier transform of the image without changing a phase component for the Fourier transform of the image to form the filtered image.

23. The apparatus of claim **22**, wherein the means for changing the amplitude component for the Fourier transform of the image without changing the phase component for the Fourier transform of the image to form the filtered image comprises:

15 a means for scaling amplitudes for the amplitude component for the Fourier transform of the image without affecting phases in the phase component for the Fourier transform using a root filter to form the
20 filtered image, wherein the root filter scales the amplitudes in a non-linear manner.

24. The apparatus of claim **21**, **22**, or **23**, wherein the means for converting the filtered image from the frequency domain back into the spatial domain to form the modified image comprises:

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a means for computing an inverse Fourier transform for the filtered image that converts the filtered image from the frequency domain to the spatial domain, wherein the intensity of the undesired feature in the modified image is increased as compared to the intensity of the undesired feature in the image.

25. The apparatus of claim **21**, **22**, **23**, or **24** further comprising:

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a means for identifying characteristics of an object in the image using the processed image.

26. The apparatus of claim **21**, **22**, **23**, or **24** further comprising:

a means for identifying an object in the image using the processed image.

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27. The apparatus of claim **21**, **22**, **23**, or **24** further comprising:

a means for determining whether an inconsistency is present in an object in the image using the processed image.

28. The apparatus of claim **27**, wherein the means for determining whether the inconsistency is present in the object using the processed image comprises:

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a means for comparing the processed image with another image of the object to form a comparison; and

a means for determining whether the inconsistency is present using the comparison.

FIG. 1

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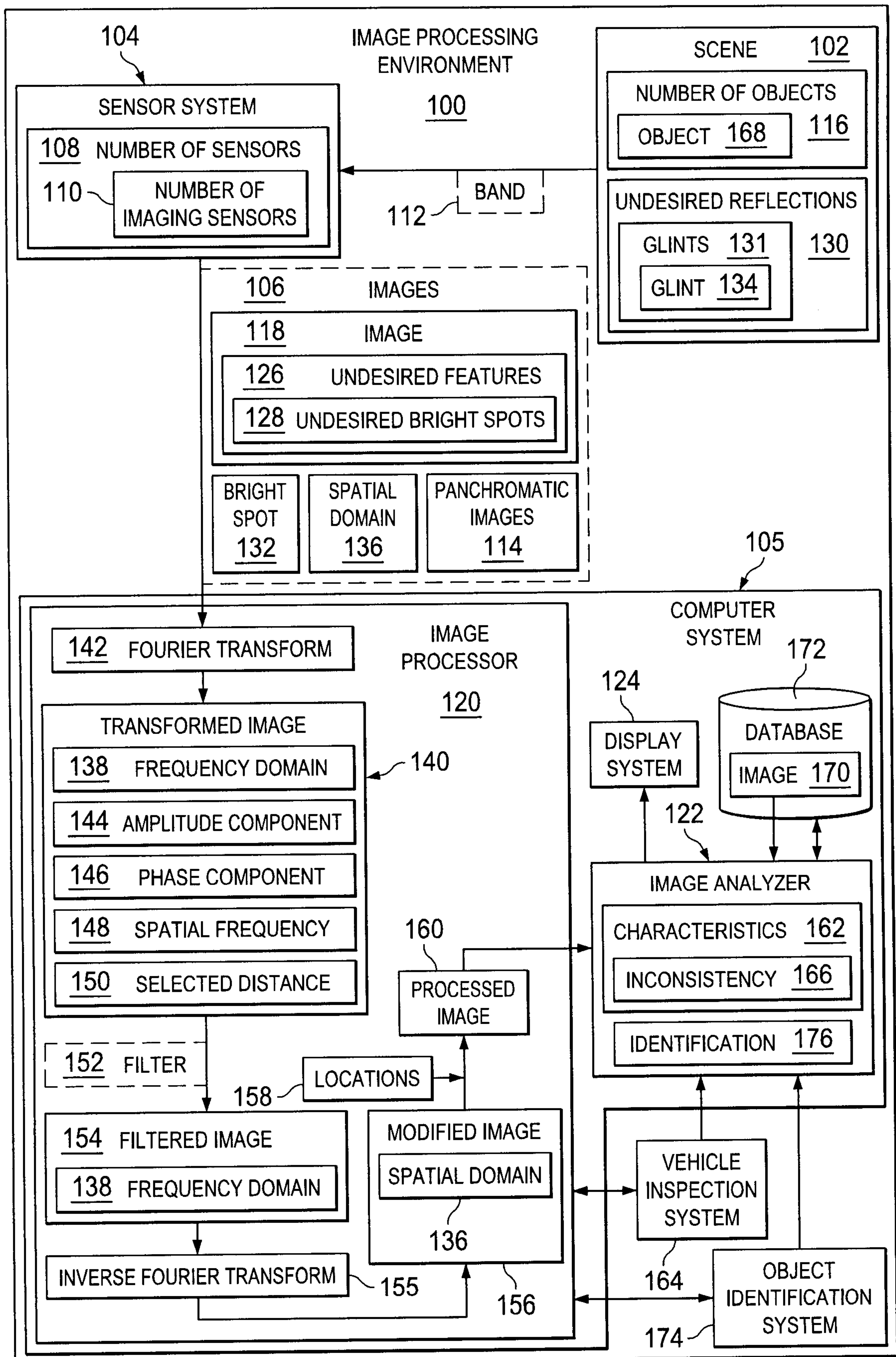
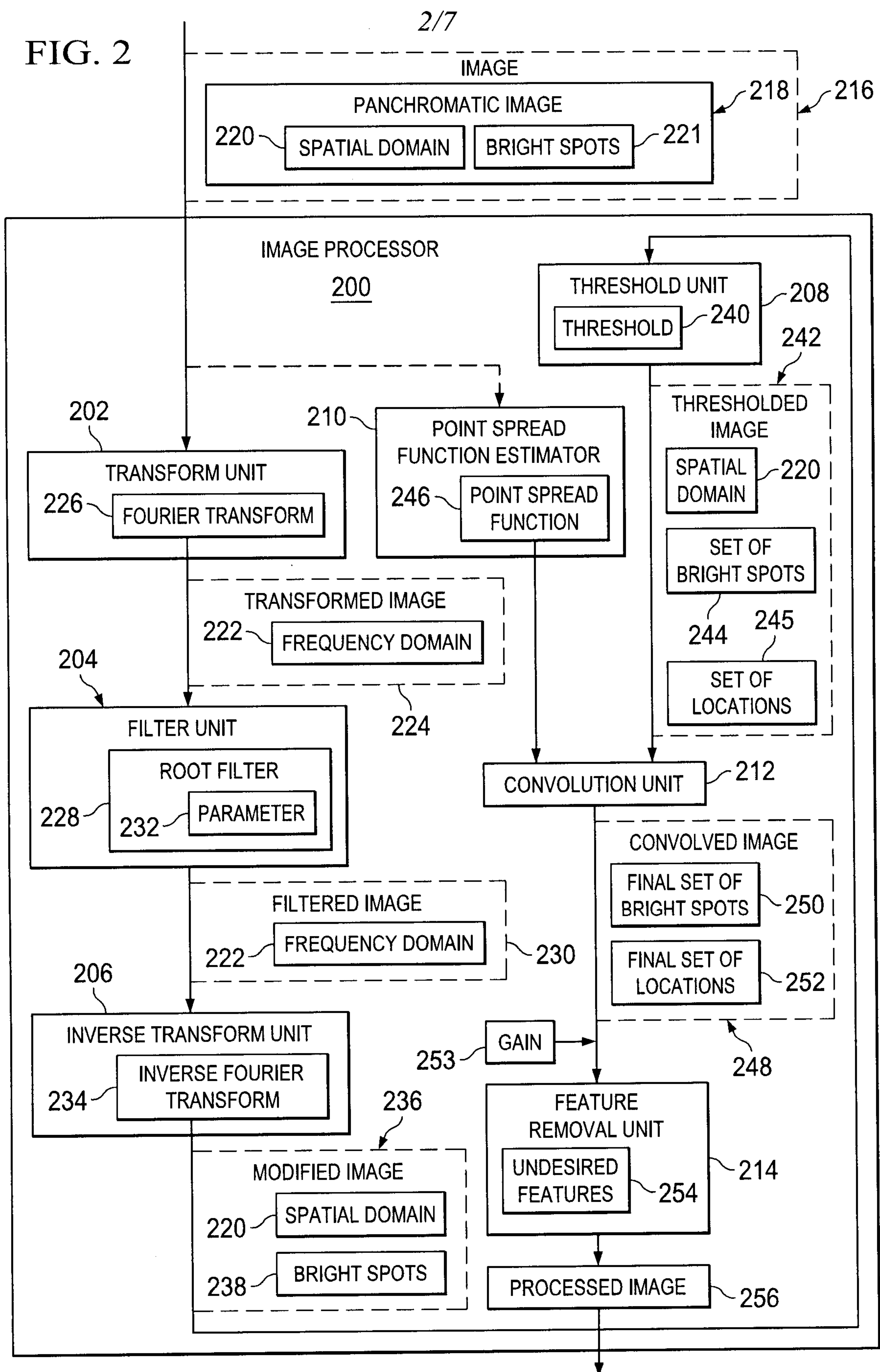
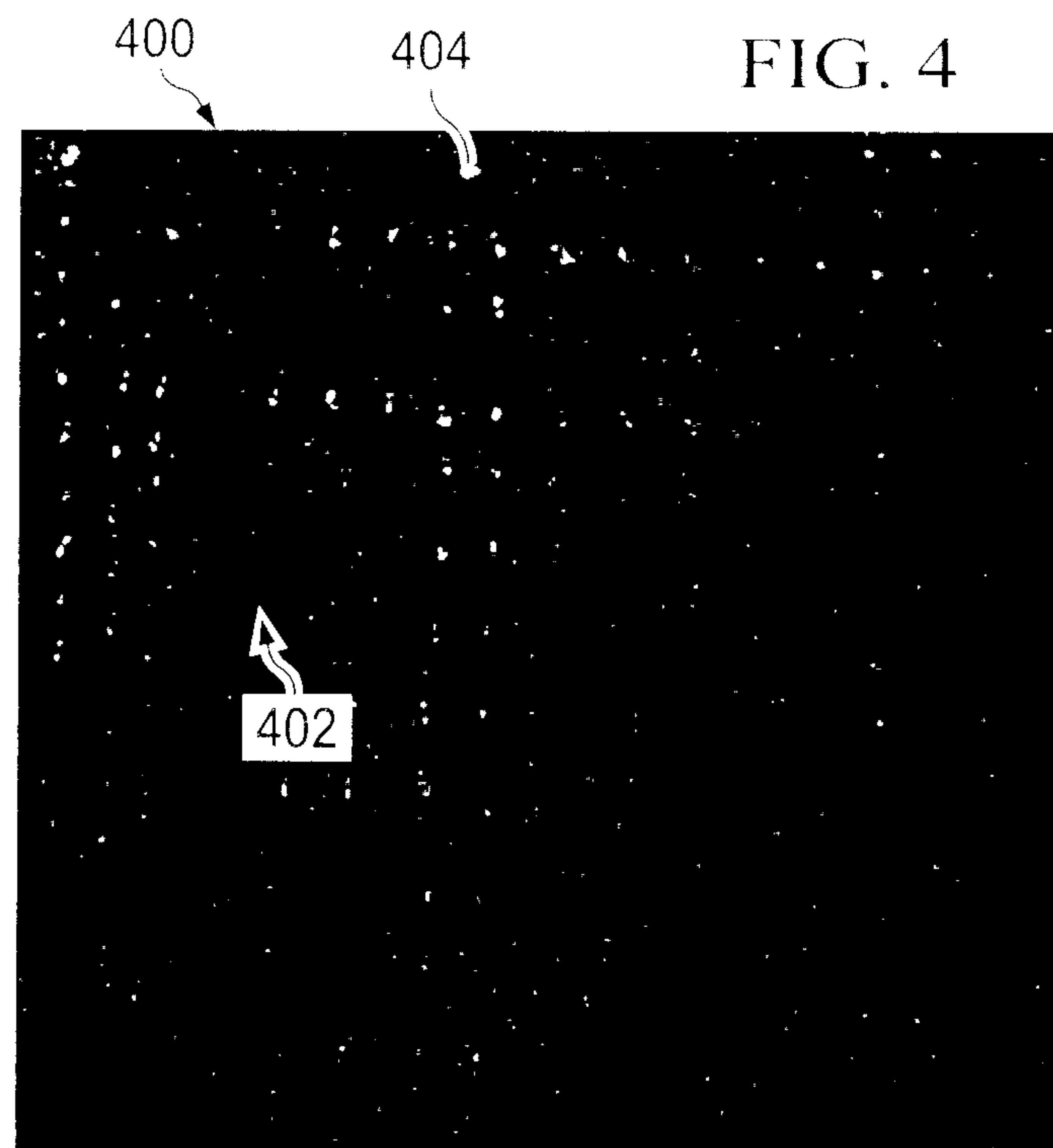
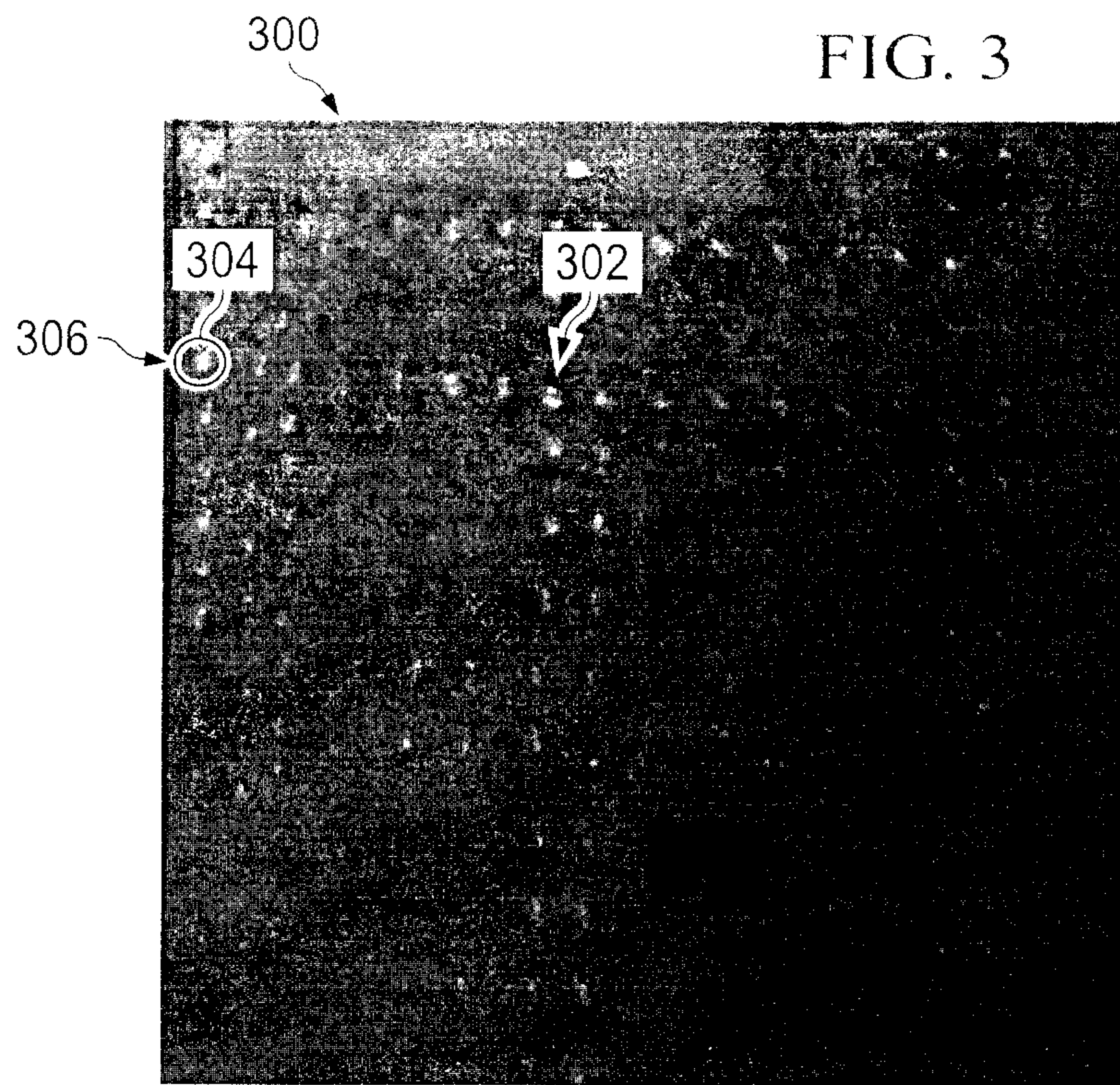


FIG. 2



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FIG. 5

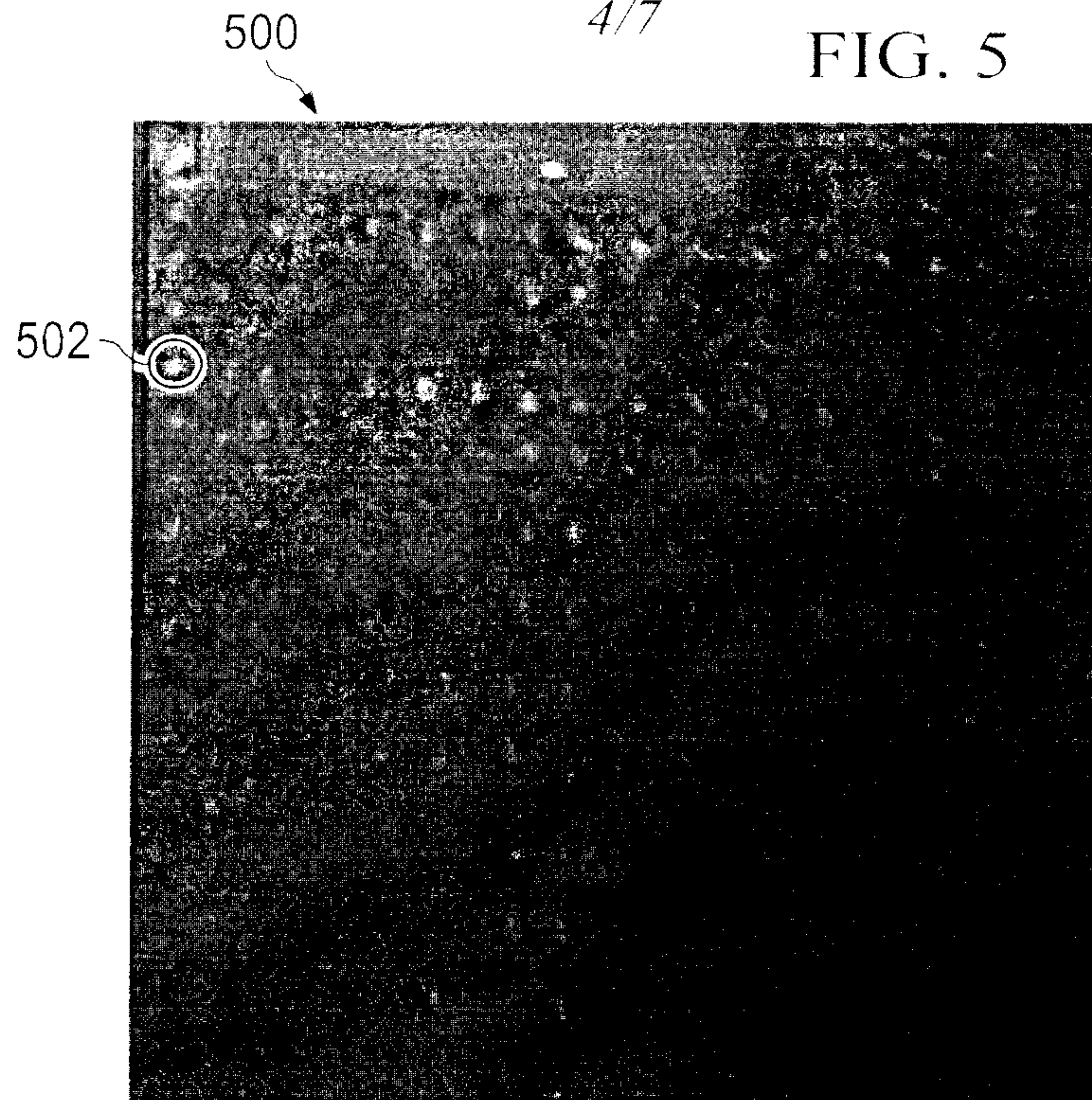
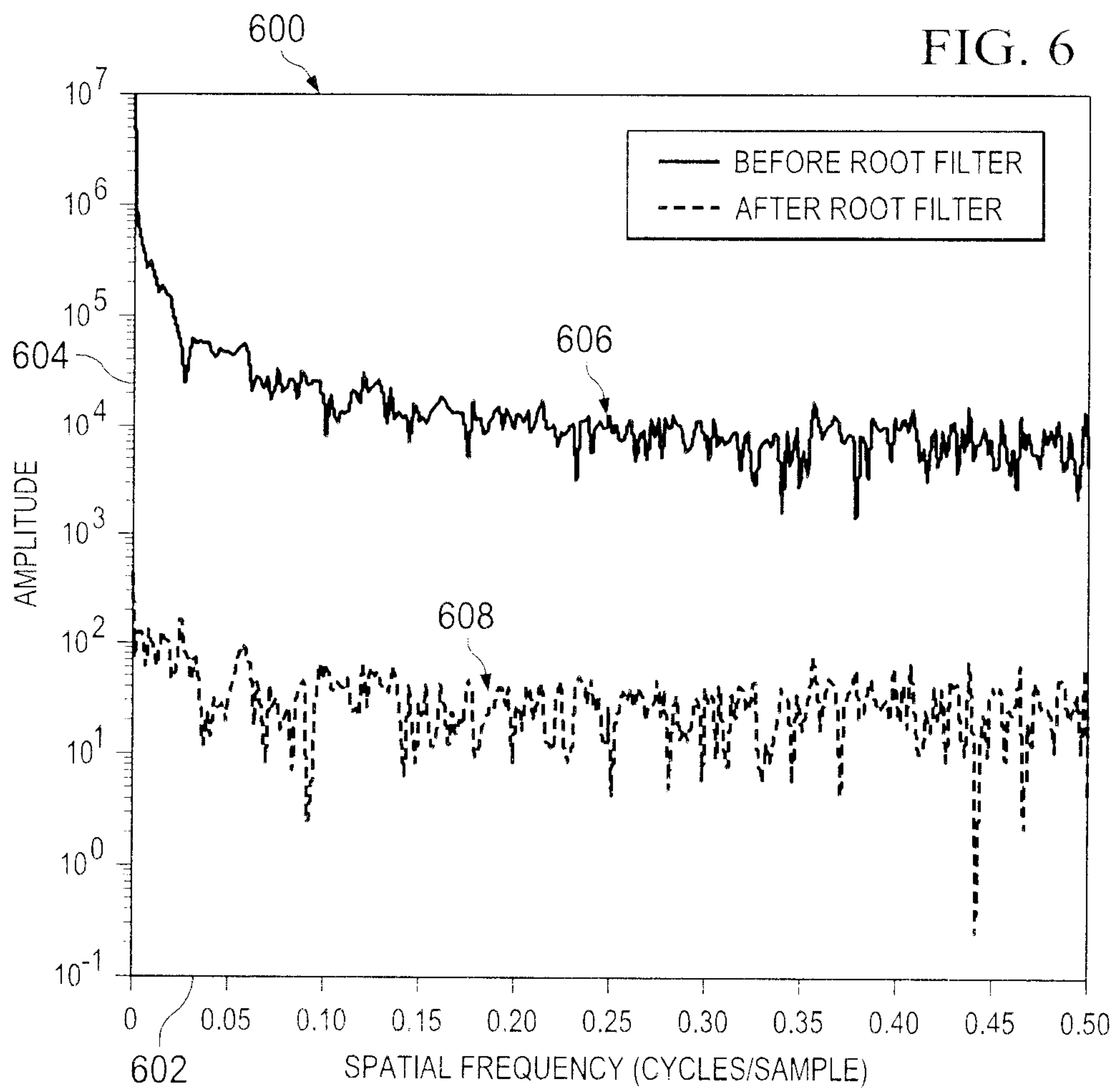


FIG. 6



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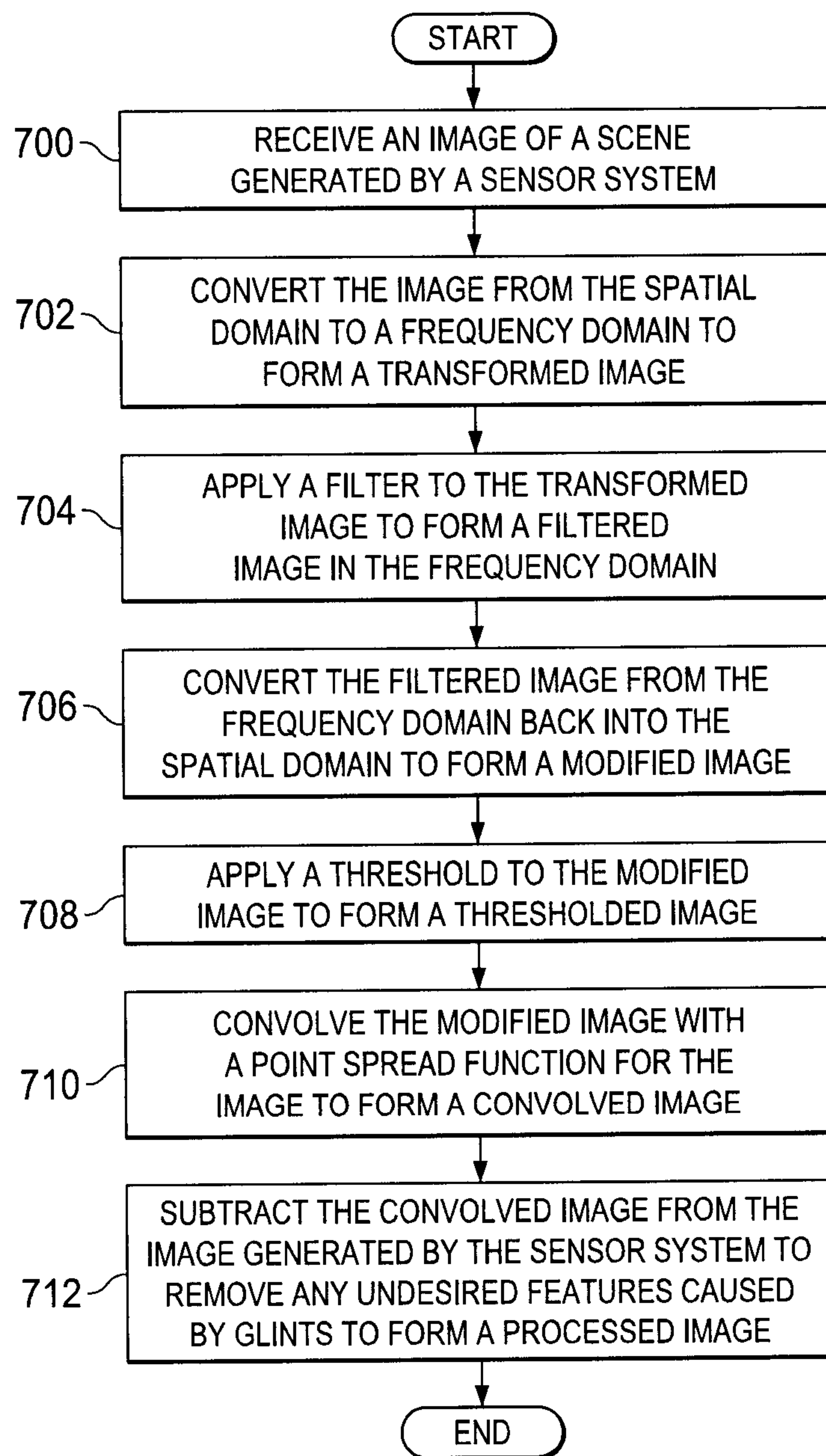


FIG. 7

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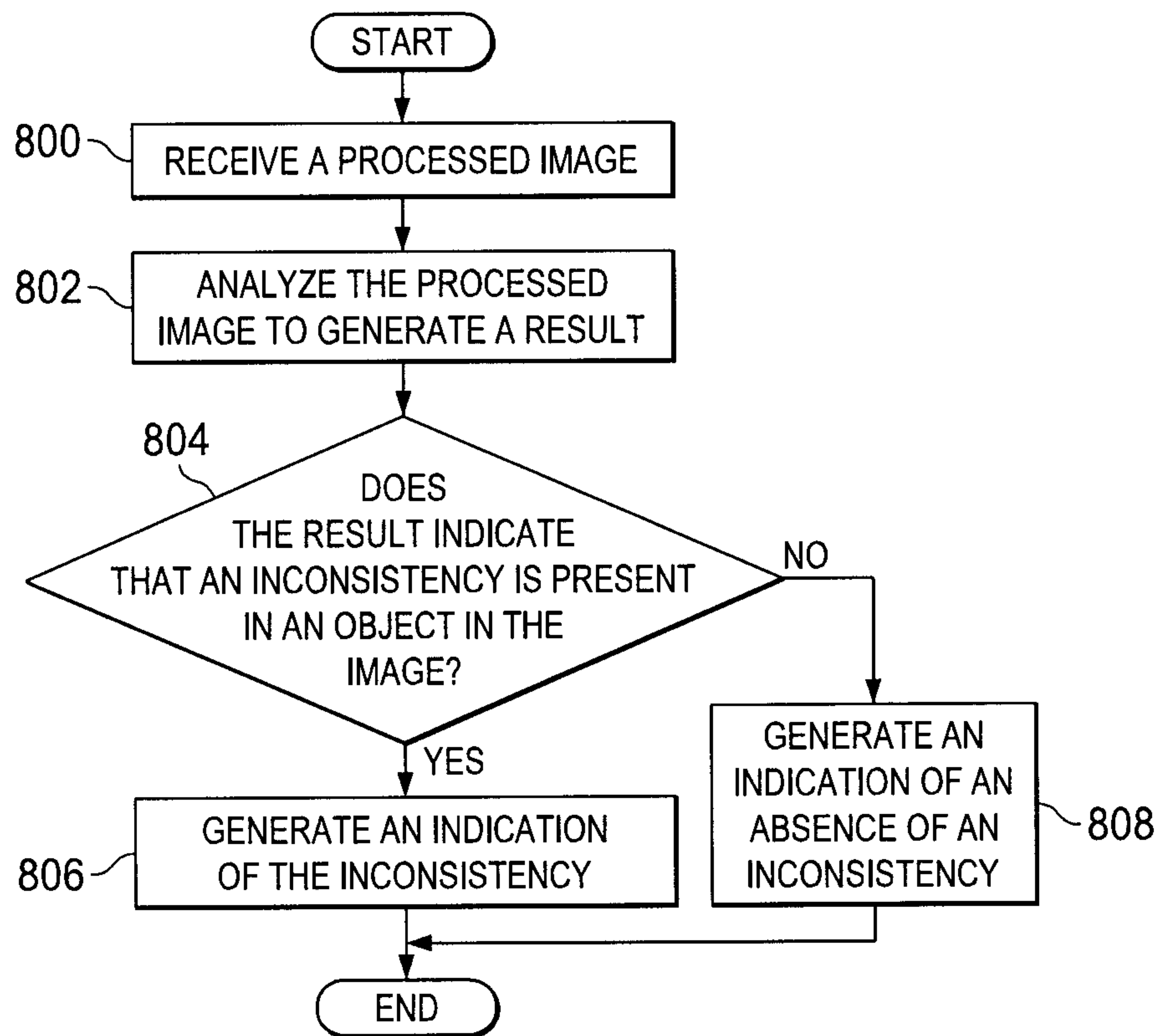


FIG. 8

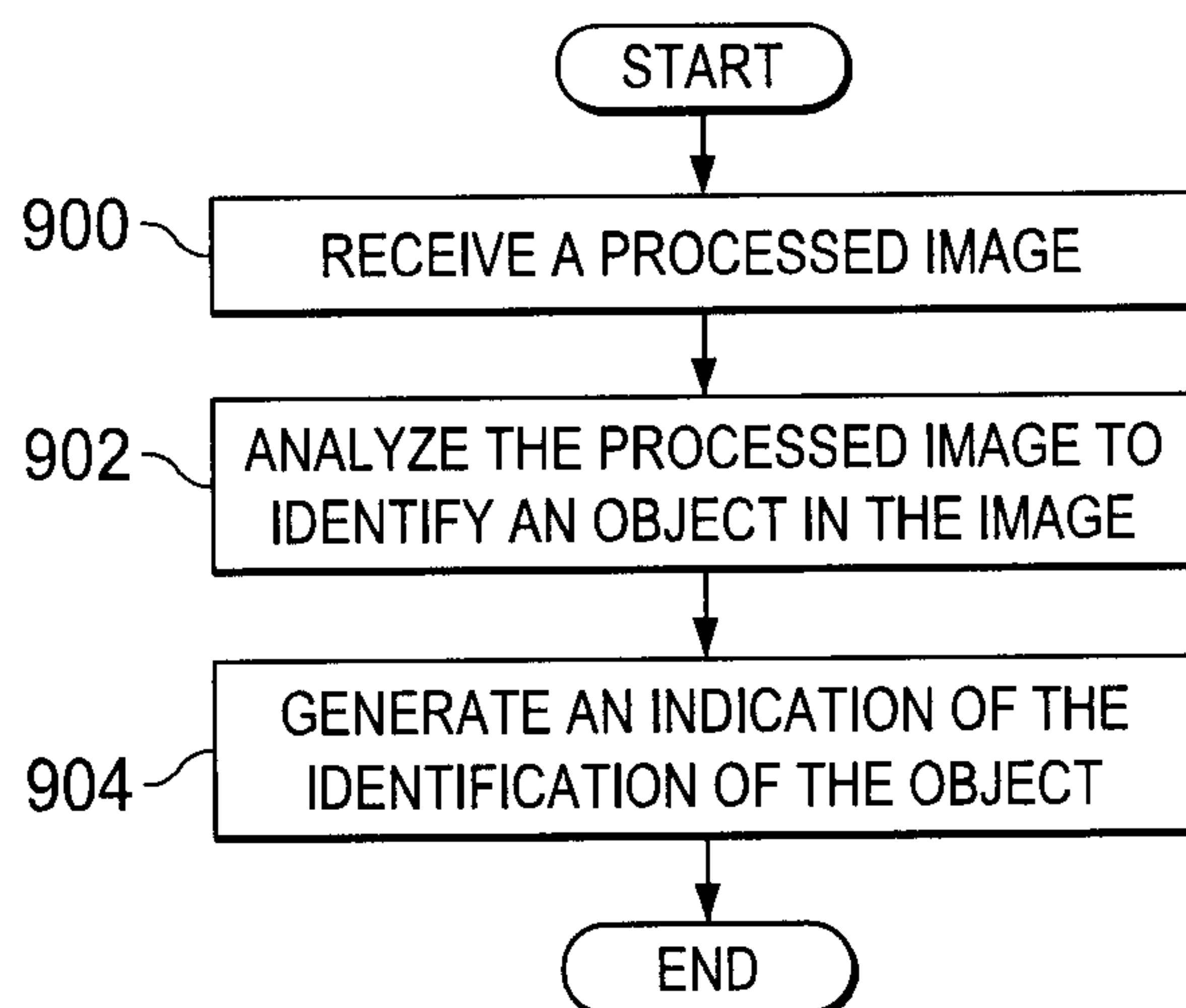


FIG. 9

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FIG. 10

