CONTAMINATION IDENTIFICATION SYSTEM

BACKGROUND

The present disclosure relates generally to manufacturing composite structures and, in particular, to inspecting composite workpieces during manufacturing. Still more particularly, the present disclosure relates to a method and apparatus for identifying contaminants on composite workpieces prior to curing the composite workpieces to form composite structures.

Aircraft are being designed and manufactured with greater and greater percentages of composite materials. Composite materials are used in aircraft to decrease the weight of the aircraft. This decreased weight improves performance features such as payload capacities and fuel efficiencies. Further, composite materials provide longer service life for various components in an aircraft.

Composite materials are tough, light-weight materials created by combining two or more functional components. For example, a composite material may include reinforcing fibers bound in polymer resin matrix. The fibers may be unidirectional or may take the form of a woven cloth or fabric. The fibers and resins are arranged and cured to form a composite material.

Further, using composite materials to create aerospace composite structures potentially allows for portions of an aircraft to be manufactured in larger pieces or sections. For example, a fuselage in an aircraft may be created in cylindrical sections to form the fuselage of the aircraft. Other examples include, without limitation, wing sections joined to form a wing or stabilizer sections joined to form a stabilizer.

In manufacturing composite structures, layers of composite material are typically laid up on a tool. The layers may be comprised of fibers in sheets. These sheets may take the form of fabrics, tape, tows, or other suitable forms. In some cases, resin may be infused or preimpregnated into the sheets. These types of sheets are commonly referred to as prepreg.

The different layers of prepreg may be laid up in different orientations and different numbers of layers may be used depending on the thickness of the composite structure being manufactured. These layers may be laid up by hand or using automated lamination equipment such as a tape laminating machine or a fiber placement system.

After the different layers have been laid up on the tool, the layers consolidated and cured upon exposure to temperature and pressure, thus forming the final composite structure. Thereafter, the composite structure may be inspected to determine whether inconsistencies are present. The inspection may be performed using x-ray inspection systems, ultrasound inspection systems, and other types of non-destructive inspection systems.

If an inconsistency is identified, the composite structure may be reworked. In some cases, the inconsistency may result in the composite structure being discarded, requiring new composite structure to be manufactured. Examples of inconsistencies that may be present in a composite structure include voids, porosity, delamination, foreign object debris (FOD), and other types of inconsistencies.

Reworking parts or discarding and remanufacturing composite structures may delay the completion of an aircraft using the composite structures. Further, reworking or discarding parts may increase the cost in manufacturing aircraft by an undesirable amount.

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

SUMMARY

In one illustrative embodiment, a method for inspecting a composite workpiece is present. A response to electromagnetic radiation directed to a surface of the composite workpiece is separated into a number of wavelengths for each of a number of locations on the surface of the composite workpiece. A set of contaminants not visible to a naked eye on the surface of the composite workpiece is identified from the number of wavelengths for the each of the number of locations. A two-dimensional image of the surface of the composite workpiece is generated with a set of graphical indicators indicating the set of contaminants identified from the number of wavelengths for the each of the number of locations on the surface of the composite workpiece.

In another illustrative embodiment, a method for inspecting a tool for laying up layers of composite material is present. A response to electromagnetic radiation directed to a surface of the tool is separated into a number of wavelengths for each of a number of locations on the surface of the tool prior to laying up the layers of

composite material on the surface of the tool. A set of contaminants is identified from the number of wavelengths for the each of the number of locations on the surface of the tool. A two-dimensional image of the surface of the tool is generated with a set of graphical indicators indicating the set of contaminants identified from the number of wavelengths for the each of the number of locations on the surface of the tool.

In still another illustrative embodiment, a method for inspecting a composite material is present. A response to infrared electromagnetic radiation directed to a surface of the composite material is separated into a number of infrared wavelengths for each of a number of locations on the surface of the composite material. A set of inconsistencies for the composite material is identified from the number of infrared wavelengths for the each of the number of locations. A two-dimensional image of the composite material with a set of graphical indicators indicating the set of inconsistencies identified from the number of infrared wavelengths for the each of the number of locations on the surface of the composite material is generated.

In yet another illustrative embodiment, an apparatus comprises a spectral sensor system and an analyzer. The spectral sensor system is configured to separate a response to electromagnetic radiation directed at a surface of a composite workpiece into a number of wavelengths comprising wavelengths outside of a visible light spectrum and generate data from the number of wavelengths of the electromagnetic radiation. The analyzer is configured to cause the spectral sensor system to generate the data from the response after a number of layers of composite material have been laid up for the composite workpiece and prior to the number of layers of composite material being cured. The analyzer is further configured to generate a two-dimensional image of the surface of the composite workpiece with a set of graphical indicators indicating a set of contaminants identified from the number of wavelengths for each of a number of locations on the surface of the composite workpiece.

The features and functions 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

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative 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 illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an illustration of a manufacturing environment in accordance with an illustrative embodiment;

Figure 2 is an illustration of a block diagram of an inspection environment in accordance with an illustrative embodiment;

Figure 3 is an illustration of a block diagram of an imaging system in accordance with an illustrative embodiment;

Figure 4 is an illustration of a block diagram of data in accordance with an illustrative embodiment;

Figure 5 is an illustration of an imaging system in accordance with an illustrative embodiment;

Figure 6 is an illustration of an imaging system in accordance with an illustrative embodiment;

Figure 7 is an illustration of an imaging system in accordance with an illustrative embodiment;

Figure 8 is an illustration of a spectral sensor system in accordance with an illustrative embodiment;

Figure 9 is an illustration of a two-dimensional image with graphical indicators in accordance with an illustrative embodiment;

Figure 10 is an illustration of a flowchart of a process for inspecting a composite workpiece in accordance with an illustrative embodiment;

Figure 11 is an illustration of a flowchart of a process for identifying a set of contaminants from a number of wavelengths in accordance with an illustrative embodiment;

Figure 12 is an illustration of a flowchart of a process for generating a two-dimensional image of a surface of a composite workpiece with a set of graphical

indicators indicating a set of contaminants in accordance with an illustrative embodiment;

Figure 13 is an illustration of a flowchart of a process for inspecting a composite workpiece in accordance with an illustrative embodiment;

Figure 14 is an illustration of a data processing system in accordance with an illustrative embodiment;

Figure 15 is an illustration of an aircraft manufacturing and service method in accordance with an illustrative embodiment; and

Figure 16 is an illustration of an aircraft in which an illustrative embodiment may be implemented.

DETAILED DESCRIPTION

The different illustrative embodiments recognize and take into account one or more different considerations. For example, the illustrative embodiments recognize and take into account that inconsistencies may be caused by contaminants during the manufacturing of a composite structure. For example, as layers of composite material are being laid up on a workpiece, contaminants may be present on the surface of one of the layers of composite material. These contaminants may already be present on the layer of composite material, originate from the manufacturing environment as the layer is placed on the workpiece, or come from some other source.

As additional layers of composite material are placed on top of the layers on which contaminants are present, the contaminants become embedded between layers of composite material. The illustrative embodiments also recognize and take into account that contaminants may be present on the surface of a tool on which the layers of composite material are laid up. These contaminants may adhere to a layer of composite material that is placed on the surface of the tool. When the contaminants take the form of liquids, these contaminants soak into one or more layers of composite material.

These contaminants may result in inconsistencies when the composite workpiece with these layers is cured. For example, without limitation, contaminants may result in undesired levels of at least one of voids, porosity, delaminations, and other types of inconsistencies. As used herein, the phrase "at least one of", when used with a list of items, means 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, 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.

The illustrative embodiments recognize and take into account that the presence of these contaminants on the surface of the layers of composite material laid up on a composite workpiece for a composite structure may be, for example, without limitation, particles, debris, liquids, moisture, and other types of undesirable contaminants. The illustrative embodiments recognize and take into account that identifying a presence of these contaminants on the surface of layers of composite material prior to curing the layers may reduce the amount of rework and the number of composite structures that are discarded. Further, when the number of composite structures discarded is reduced, the number of replacement composite structures manufactured also is reduced.

The illustrative embodiments also recognize and take into account that these contaminants are often not visible to the naked eye. Consequently, inspecting the layers of composite materials for contaminants may be more difficult than desired during manufacturing of composite structures from the layers of composite materials.

Thus, the illustrative embodiments provide a method and apparatus for inspecting composite workpieces. In these illustrative examples, a composite workpiece may be a number of layers of composite material that have been laid up for a composite structure. The process may direct electromagnetic radiation to a surface of the composite workpiece. A response to the electromagnetic radiation directed at the surface of the composite workpiece is separated into a number of wavelengths for each of a number of locations on the surface.

A two-dimensional image of the surface of the composite workpiece is generated with a set of graphical indicators indicating a set of contaminants identified from the number of wavelengths for each of the set of locations. As used herein, a "set of" when used with reference to items means zero, one, or more items. For example, a set of contaminants is zero or more contaminants. In other words, a set of contaminants may sometimes be an empty set when contaminants are not identified. The two-dimensional image may be used to determine whether contaminants are present and to identify where action should be taken if contaminants are present.

Turning now to **Figure 1**, an illustration of a manufacturing environment is depicted in accordance with an illustrative embodiment. In this depicted example, manufacturing environment **100** includes composite layup station **102** and composite layup station **104**.

Composite layup station **102** and composite layup station **104** are stations at which layers of composite material may be laid up when manufacturing composite structures. In this illustrative example, composite layup system **106** may place layers of composite material **108** onto tool **110** for composite workpiece **112** at composite layup station **102**. In this illustrative example, composite layup system **106** is a robotic arm on which an end effector is present for laying up layers of composite material **108**.

In these illustrative examples, inspection of surface **114** of layer **116** in layers of composite material **108** is made prior to curing layers of composite material **108**. In this illustrative example, the inspection may be made using inspection system **118**.

Inspection system **118** comprises housing **120**, imaging system **122**, light source **124**, and computer **126**. Housing **120** is moveable on platform **128**. In this illustrative example, platform **128** includes rail system **130** and housing **120**. Housing **120** in platform **128** holds imaging system **122** and light source **124**.

Light source **124** is configured to direct light to locations on surface **114** of composite workpiece **112**. In particular, light is directed to surface **114** of layer **116** in layers of composite material **108** that form composite workpiece **112**.

Imaging system **122** is configured to receive a response to the light directed by light source **124** onto locations on surface **114** of composite workpiece **112**. Imaging system **122** is configured to separate the response for each location on surface **114** into a number of wavelengths. This data is sent to computer **126**. In other words, a response may be detected for each location and a number of wavelengths generated for that particular location from the response detected. In this illustrative example, the data is sent from imaging system **122** to computer **126** over wireless communications link **132**.

Computer **126** identifies any contaminants that may be present at the locations using the data. Computer **126** is configured to generate a two-dimensional image of surface **114**. In the illustrative examples, the two-dimensional image may be a two-dimensional spectrogram response of surface **114**. The image may include

graphical indicators indicating contaminants identified using the data for each of the locations.

This image may be used by operator **134** to identify any contaminants that may be present on surface **114** of composite workpiece **112**. Further, the image also may be used to identify the locations at which contaminants are present on surface **114** of composite workpiece **112**.

In these illustrative examples, this identification of the contaminants is performed prior to curing composite workpiece **112**. In this manner, the contaminants may be removed from composite workpiece **112**. For example, the contaminants may be particles that are removed. In other examples, if the contaminants cannot be removed from composite workpiece **112**, one or more of layers of composite material **108** may be replaced such that the contaminants are no longer present.

In another illustrative example, composite layup station **104** includes tool **136** and composite layup system **138**. In this illustrative example, composite layup system **138** includes a platform on which a composite layup unit may move relative to tool **136** to lay up layers of composite material on tool **136**.

In this illustrative example, inspection system **140** includes imaging system **142** associated with robotic arm **144** and light source **146** associated with robotic arm **148**. Robotic arm **144** and robotic arm **148** form platform **150** for inspection system **140** in this illustrative example. Inspection system **140** also includes computer **126**.

When one component is "associated" with another component, the association is a physical association in these depicted examples. For example, a first component, imaging system **142**, may be considered to be associated with a second component, robotic arm **144**, by being secured to the second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component using a third component. The first component may also be considered to be associated with the second component by being formed as part of and/or an extension of the second component.

Robotic arm **148** moves light source **146** to direct light to different locations on surface **152** of tool **136** in these illustrative examples. Imaging system **142**

may be moved by robotic arm **144** to detect a response to the light directed to surface **152** of tool **136** for each of the locations on surface **152**. In a similar fashion, imaging system **142** generates data comprising a number of wavelengths for one of the locations on surface **152** on tool **136**.

This data is sent to computer **126** over wireless communications link **154**. Computer **126** analyzes this data to determine whether contaminants are present on surface **152** of tool **136**. Computer **126** is also configured to generate a two-dimensional image of surface **152** of tool **136**. The two-dimensional image also may include graphical indicators identifying any contaminants that have been detected on surface **152** of tool **136**.

Operator **156** may use this image to determine whether contaminants are present. Further, operator **156** may remove the contaminants from surface **152** of tool **136** prior to using composite layup system **138** to layup composite material on tool **136**. Contaminants on surface **152** of tool **136** may be transferred onto one or more layers of composite materials laid up on surface **152**. These contaminants may also result in inconsistencies when the layers of composite materials are cured to form the composite structure.

By inspecting surface **152** of tool **136** prior to laying up composite materials on surface **152** of tool **136**, contaminants on surface **152** of tool **136** may be identified and removed. As a result, the occurrence of inconsistencies on a composite structure caused by contaminants on surface **152** of tool **136** may be reduced.

In this manner, issues with contaminants causing inconsistencies in composite structures may be reduced. By performing inspections prior to curing composite workpiece **112**, the composite structure resulting from composite workpiece **112** is less likely to have inconsistencies as compared to currently used manufacturing processes for composite structures.

Turning now to **Figure 2**, an illustration of a block diagram of an inspection environment is depicted in accordance with an illustrative embodiment. Inspection system **118** and inspection system **140** in manufacturing environment **100** are examples of physical implementations for components in inspection environment **200** in **Figure 2**.

In this illustrative example, inspection system **202** in inspection environment **200** may be used to perform inspection of tool **204**, composite workpiece **206**, or both tool **204** and composite workpiece **206**.

In these illustrative examples, number of layers of composite materials **208** forms composite workpiece **206**. Number of layers of composite materials **208** is laid up on tool **204** during manufacturing of composite workpiece **206**.

In these illustrative examples, set of contaminants **210** may be present on surface **212** of composite workpiece **206**. In other words, set of contaminants **210** is present on surface **212** on number of layers of composite materials **208**. In these illustrative examples, set of contaminants **210** is present on surface **212** of a layer of composite material that is not covered by another layer of composite material in number of layers of composite materials **208**.

In these illustrative examples, an inspection of surface **212** of number of layers of composite materials **208** may be performed prior to curing composite workpiece **206**. In particular, this inspection may be performed before additional layers of composite materials are placed on top of surface **212** of number of layers of composite materials **208**.

As depicted, the inspection may be performed using inspection system **202**, which takes the form of non-destructive inspection system **214** in these illustrative examples. Inspection system **202** may include imaging system **216**, electromagnetic radiation source **218**, platform **220**, and analyzer **222**.

Platform **220** is a hardware system that may include software. Platform **220** may be stationary or may be mobile.

Imaging system **216** and electromagnetic radiation source **218** may be associated with platform **220**. In some illustrative examples, analyzer **222** also may be associated with platform **220**. Platform **220** provides support for these and any other components.

Additionally, platform **220** may be configured to move components associated with platform **220** such as, for example, imaging system **216** and electromagnetic radiation source **218**. As depicted, platform **220** may include movement system **223** configured to move at least one of platform **220** and composite workpiece **206**.

Electromagnetic radiation source **218** is a hardware device and may include software. Electromagnetic radiation source **218** is configured to generate electromagnetic radiation **224**. Electromagnetic radiation source **218** is configured to

direct electromagnetic radiation **224** to number of locations **226** on surface **212** of composite workpiece **206**.

In these illustrative examples, electromagnetic radiation source **218** may take various forms. For example, without limitation, electromagnetic radiation source **218** may be a laser system, a halogen light system, a light emitting diode system, a xenon arc lamp system, a laser diode system, a tunable laser system, a quartz lamp system and other suitable types of electromagnetic radiation sources. Electromagnetic radiation **224** may be at least one of visible light, infrared light, and other suitable types of electromagnetic radiation.

Imaging system **216** is a hardware device and may include software. Imaging system **216** is configured to receive and process response **228**. Response **228** is a response to electromagnetic radiation **224** directed to number of locations **226** on surface **212** of composite workpiece **206**. Response **228** to electromagnetic radiation **224** directed to surface **212** of composite workpiece **206** is separated into number of wavelengths **230** for each of number of locations **226**.

Data **232** is generated by imaging system **216** from response **228**. For example, data **232** includes data generated from number of wavelengths **230** separated out from response **228** for each of number of locations **226**. In these illustrative examples, data **232** includes an intensity for each wavelength in number of wavelengths **230** for a particular location in number of locations **226**. The portion of data **232** for a particular location in number of locations **226** forms a signature in these examples. Thus, number of signatures **233** may be present for number of locations **226** in data **232**.

Data **232** is sent from imaging system **216** to analyzer **222** over communications link **229**. Communications link **229** may be a wired communications link, a wireless communications link, an optical communications link, or some other suitable type of communications link.

Analyzer **222** is a hardware device and may include software. In these illustrative examples, analyzer **222** may be implemented using computer system **238**. Computer system **238** is comprised of a number of computers. When more than one computer is present, those computers may be in communication with each other using a communications medium such as a network.

Analyzer **222** is configured to generate image **234** using data **232**. Image **234** may be displayed by computer system **238**. Image **234** may be displayed using a display device such as a liquid crystal display or other suitable type of display device. In these illustrative examples, image **234** takes the form of two-dimensional image **236**.

In these illustrative examples, analyzer **222** identifies set of contaminants **210** on surface **212** of composite workpiece **206**. As discussed above, set of contaminants **210** may be an empty set in which no contaminants are present.

Analyzer **222** identifies set of contaminants **210** using signature database **240**. For example, analyzer **222** compares data **232** to signature database **240** to determine whether contaminants are present. More specifically, number of signatures **233** is compared to signatures **241** in signature database **240**. In these illustrative examples, signature database **240** is a database of wavelengths for known contaminants.

Signatures **241** contain information materials. These materials may include at least one of contaminants, composite materials expected to be present, and other materials. In these illustrative examples, a signature of a material comprises a number of intensities for a number of wavelengths that is present for the contaminant. The intensities for different wavelengths for a material form the signature for that particular material. These intensities at the different wavelengths are unique for a material in these illustrative examples.

As a result, the intensities for the number of wavelengths **230** in data **232** may be compared to signatures **241** to determine whether a contaminant is present. Signature database **240** also may be used to identify materials that are expected to be present in composite workpiece **206**.

Thus, analyzer **222** may also identify the types of composite materials used in number of layers of composite materials **208**. In this manner, analyzer **222** may also determine whether number of layers of composite materials **208** is the desired type of composite materials for use in composite workpiece **206**.

In these illustrative examples, set of graphical indicators **242** are included in image **234**. Set of graphical indicators **242** are used to identify set of contaminants **210** for each of number of locations **226** on surface **212** of composite workpiece **206**. In other words, each location in number of locations **226** may have no contaminants, or one or more contaminants.

In these illustrative examples, set of graphical indicators **242** is included in number of locations **244** in image **234** corresponding to number of locations **226** on surface **212** of composite workpiece **206**. In other words, a graphical indicator in set of graphical indicators **242** used to identify a contaminant in set of contaminants **210** may be placed in a location within number of locations **244** in image **234** such that the location corresponds to the location in number of locations **226** on surface **212** where the contaminant is present.

In other words, the placement of set of graphical indicators **242** in number of locations **244** are such that an operator may identify the corresponding locations in number of locations **226** when looking at surface **212** of composite workpiece **206**. Further, set of graphical indicators **242** also may include graphical indicators that indicate an absence of a contaminant on surface **212** in some illustrative examples.

Additionally, in some illustrative examples, analyzer **222** may project image **234** onto surface **212** of composite workpiece **206**. This projection of image **234** may be performed by imaging system **216**. The projection of image **234** onto surface **212** of composite workpiece **206** is such that set of graphical indicators **242** is displayed on set of contaminants **210** on surface **212** of composite workpiece **206**. In these illustrative examples, set of graphical indicators **242** may have a one to one ratio such that the graphical indicators show the actual size of contaminants within set of contaminants **210** when image **234** with set of graphical indicators **242** is projected onto surface **212** of composite workpiece **206**.

In these illustrative examples, the steps of separating response **228** into number of wavelengths **230** for each of number of locations **226** on surface **212**, identifying set of contaminants **210** from number of wavelengths **230** for each of number of locations **226** on surface **212**, and generating image **234** are performed when number of layers of composite materials **208** are laid up for composite workpiece **206**. In particular, these steps are performed prior to curing composite workpiece **206** to form composite structure **246**. In these illustrative examples, composite structure **246** may be a composite aircraft part. These steps may be performed each time one or more layers of composite materials are laid up for composite workpiece **206**.

By inspecting surface **212** prior to curing composite workpiece **206**, contaminants may be found through the inspection before curing composite workpiece **206** to form composite structure **246**. When contaminants are identified before curing

composite workpiece **206**, the contaminants may be removed. The removal of contaminants may be, for example, removing particles, evaporating liquids, or other suitable operations. In some illustrative examples, the contaminants may be removed by replacing one or more of the number of layers of composite materials **208** on which contaminants are identified.

Turning now to **Figure 3**, an illustration of a block diagram of an imaging system is depicted in accordance with an illustrative embodiment. In this illustrative example, components that may be used in imaging system **216** in **Figure 2** are shown. As depicted, imaging system **216** includes spectral sensor system **300**, visible light sensor system **302**, director system **304**, projector **306**, controller **307**, and platform **308**.

In these illustrative examples, spectral sensor system **300**, visible light sensor system **302**, director system **304**, projector **306**, and controller **307** are associated with platform **308**. Platform **308** is a structure that may take various forms. For example, without limitation, platform **308** may be at least one of a frame, a rail system, a housing, a robotic arm, and some other suitable type of structure. For example, platform **308** may be a housing in which one or more of these different components in imaging system **216** may be located.

Spectral sensor system **300** is a hardware system and is configured to receive response **228** and generate data **232** for number of wavelengths **230** from **Figure 2**. In these illustrative examples, spectral sensor system **300** is configured to generate number of wavelengths **230** in the form of a range of wavelengths. This range of wavelengths may be continuous or may include gaps depending on the particular implementation.

Spectral sensor system **300** includes filter **310**, and sensor array **312** in this illustrative example. Filter **310** is configured to separate electromagnetic radiation in response **228** into number of wavelengths **230**. In these illustrative examples, filter **310** takes the form of interference filter **314**.

Each of the wavelengths in number of wavelengths **230** separated by filter **310** is sent to a sensor in sensor array **312** in these illustrative examples. As a result, sensor array **312** generates data from number of wavelengths **230** from response **228** from a particular location in number of locations **244**.

In these illustrative examples, director system **304** is a hardware system that is configured to direct response **228** onto filter **310**. Director system **304** may cause response **228** to be scanned across filter **310**. As response **228** is scanned across filter **310**, number of wavelengths **230** is separated out in response **228** by filter **310**.

Director system **304** may be comprised of components such as mirror system **318**, opening **320**, and other suitable types of components. Mirror system **318** may be moveable to cause response **228** to scan across filter **310**. Opening **320** may be, for example, an opening in platform **308** that allows a portion of response **228** that corresponds to a location in number of locations **244** to be directed onto filter **310**.

Visible light sensor system **302** is configured to generate image data of surface **212** of composite workpiece **206** in these illustrative examples. Visible light sensor system **302** may be implemented using any type of visible light camera or components from a visible light camera.

Projector **306** is configured to project images. In these illustrative examples, projector **306** may be configured to project image **234** onto surface **212** of composite workpiece **206**.

Controller **307** is a hardware device and may include software. Controller **307** is configured to control the operation of at least one of spectral sensor system **300**, visible light sensor system **302**, director system **304**, and projector **306**. Controller **307** also may be configured to process some of data **232** generated by imaging system **216** prior to data **232** being sent to analyzer **222**. Controller **307** may be a processor unit, an integrated circuit system, a computer, or some other suitable hardware device. For example, controller **307** may pre-process data **232** to remove noise, add timestamps, and perform other operations on data **232** prior to sending data **232** to analyzer **222**.

Turning now to **Figure 4**, an illustration of a block diagram of data is depicted in accordance with an illustrative embodiment. In this figure, examples of information that may be present in data **232** in **Figure 2** are illustrated. In this illustrative example, data **232** represents data for location **400**. Location **400** is an example of a location within number of locations **244** in **Figure 2**.

Location **400** is a location identified on surface **212** of composite workpiece **206**. Location **400** may be described in terms of coordinates. For example, a coordinate system for the workpiece may be used to identify location **400**. Of course, any suitable coordinate system may be used to identify location **400**. Location **400** may

be identified in a number of different ways. For example, location **400** may be identified using a model of composite structure **246**. In particular, the model may be a model of the layups for number of composite layers **208**. This model may include a coordinate system. This coordinate system may be used by analyzer **222** to control imaging system **216** in selecting location **400**. In these illustrative examples, the model may be a computer-aided design model of composite structure **246**.

In this illustrative example, location **400** has intensities **404** for wavelengths **406**. In other words, each wavelength in wavelengths **406** has an intensity in intensities **404**.

In these illustrative examples, an intensity in intensities **404** may be measured as lux, which is luminous flux per unit area.

Wavelengths **406** are a range of wavelengths that are continuous in these illustrative examples. The wavelengths in wavelengths **406** may vary depending on the particular implementation. For example, wavelengths **406** may be from about 500 nanometers to about 3,600 nanometers. Of course, other wavelengths may be used and the wavelengths may even be discontinuous in some illustrative examples.

In these illustrative examples, intensities **404** for wavelengths **406** at location **400** form signature **408** for location **400**. Signature **408** may be compared to known signatures in signature database **240** to determine whether a contaminant is present at location **400** in these illustrative examples.

The illustration of inspection environment **200** and the different components in **Figures 2-4** are not meant to imply physical or architectural limitations to the manner in which inspection environment **200** may be implemented. Other components in addition to 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, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

For example, spectral sensor system **300**, visible light sensor system **302**, and projector **306** may be associated with different platforms rather than the same platform. In some illustrative examples, controller **307** may be located in computer system **238** at a location remote to platform **308**.

In another illustrative example, imaging system **216** may include other components in addition to the ones illustrated in **Figure 3**. For example, imaging system **216** also may include a lens system. The lens system may be configured to focus light that may be received in response **228**.

In another illustrative example, composite workpiece **206** may be processed to form composite structure **246** in other forms other than a composite aircraft part for an aircraft. For example, without limitations, composite structure **246** may be a part for a platform, such as a mobile platform, a stationary platform, a land-based structure, an aquatic-based structure, and a space-based structure. More specifically, the platform may be 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, and other suitable objects.

Turning now to **Figure 5**, an illustration of an imaging system is depicted in accordance with an illustrative embodiment. As depicted, imaging system **500** is an example of a physical implementation of imaging system **216** shown in block form in **Figure 2** and **Figure 3**.

In this depicted example, imaging system **500** may direct electromagnetic radiation **502** in the form of coherent light **504** to scan composite workpiece **506** laid up on tool **508**. In particular, coherent light **504** may be configured to be scanned in the direction of arrow **510** across surface **512** of composite workpiece **506**. In this depicted example, composite workpiece **506** is a composite workpiece for a wing of an aircraft.

In this illustrative example, coherent light **504** may cover width **514** of composite workpiece **506** while moving in the direction of arrow **510**. In response to coherent light **504**, response **516** is returned to imaging system **500**. As depicted, response **516** is a response for position **520** along length **518** of composite workpiece **506**. Response **516** is the response that may be separated into wavelengths.

More specifically, a plurality of locations is present along width **514** for each position along length **518** of composite workpiece **506**. For example, position **520** has plurality of locations **522**. Each location in plurality of locations **522** may reflect coherent light **504** in a manner that generates a portion of response **516**. The portion of response **516** corresponding to a position in plurality of locations **522** is separated into one or more wavelengths to generate data for that particular location in plurality of locations **522** at position **520**.

In these illustrative examples, coherent light **504** may be steered by imaging system **500** while imaging system **500** is stationary. In other illustrative examples, imaging system **500** may move in the direction of arrow **510**. In some illustrative examples, a combination of the two may occur to cause coherent light **504** to scan composite workpiece **506** in the direction of arrow **510** along length **518** of composite workpiece **506**.

Referring now to **Figure 6**, an illustration of an imaging system is depicted in accordance with an illustrative embodiment. Imaging system **600** is an example of one implementation for imaging system **216** shown in block form in **Figure 2** and **Figure 3**. Imaging system **600** comprises electromagnetic radiation source **602**, director system **604**, spectral sensor system **606**, and housing **607**.

Electromagnetic radiation source **602** is configured to generate electromagnetic radiation in the form of coherent light. Electromagnetic radiation source **602** takes the form of a laser system in this particular example.

As depicted, electromagnetic radiation source **602** generates beam of coherent light **620**. Beam of coherent light **620** passes through scanning mirror **610** and is reflected off of scanning mirror **608** toward surface **622** of composite workpiece **624**.

Scanning mirror **610** is reflective in one direction such that beam of coherent light **620** may pass through scanning mirror **610**. Scanning mirror **610** may be a half silver mirror.

As depicted, scanning mirror **608** is configured to direct electromagnetic radiation from electromagnetic radiation source **602** toward a composite workpiece. However, alternative embodiments may not include scanning mirror **608**. In alternative embodiments, electromagnetic radiation source **602** may be directed at a composite workpiece. In such alternative embodiments, electromagnetic radiation source **602** may or may not be located within housing **607** of imaging system **600**. Further, additional optics or directing means may be present in alternative embodiments to control electromagnetic radiation directed to a composite workpiece from electromagnetic radiation source **602**.

Director system **604** is an example of an implementation for director system **304** shown in block form in **Figure 3**. Director system **604** directs beam of coherent light **620** from electromagnetic radiation source **602** to surface **622** of composite workpiece **624**. Director system **604** also directs response **626** to beam of

coherent light **620** from surface **622** of composite workpiece **624** to spectral sensor system **606**.

As depicted, director system **604** comprises scanning mirror **608** and scanning mirror **610**. However, in alternative embodiments, director system **604** may comprise more or less components. Further, in alternative embodiments, director system **604** may include different directing components such as a rotating polygon, a rotating mirror monogon, or a prismatic polygon.

As depicted, scanning mirror **608** is connected to driving mechanism **612**. Driving mechanism **612** controls the position of scanning mirror **608**. Driving mechanism **612** may be implemented using a motor or other device that is configured to control the position of scanning mirror **608**.

The position of scanning mirror **608** controls the direction of beam of coherent light **620** toward composite workpiece **624**. As a result, movement of scanning mirror **608** may cause beam of coherent light **620** to be directed toward different locations on surface **622** of composite workpiece **624**. Thus, scanning mirror **608** may be moved by driving mechanism **612** such that beam of coherent light **620** scans surface **622** of composite workpiece **624**.

Likewise, the position of scanning mirror **610** directs response **626** received from the composite workpiece **624**. In these illustrative examples, response **626** is directed by the position of scanning mirror **610** to different portions of spectral sensor system **606** within imaging system **600**.

Scanning mirror **610** is connected to driving mechanism **614**. Driving mechanism **614** controls the position of scanning mirror **610**. Like scanning mirror **608**, the position of scanning mirror **610** directs response **626** to different portions of spectral sensor system **606** in imaging system **600**. In particular, response **626** may be directed toward different locations on spectral sensor system **606** to cause the generation of different wavelengths for a particular location on surface **622** of composite workpiece **624**. In turn, spectral sensor system **606** separates response **626** into a number of wavelengths. Spectral sensor system **606** then generates data from the number of wavelengths separated from response **626**.

In one illustrative example, director system **604** is adjusted to sample from a location on a composite workpiece. Scanning mirror **608** of director system **604** is positioned by driving mechanism **612** to an identified position. The identified position of

scanning mirror **608** is calculated to direct beam of coherent light **620** from electromagnetic radiation source **602** to a selected location on surface **622** of composite workpiece **624**. Scanning mirror **610** of director system **604** is positioned by driving mechanism **614** to an identified position. The identified position of scanning mirror **610** is calculated to direct a response received from scanning mirror **608** to spectral sensor system **606**.

After director system **604** is adjusted, electromagnetic radiation source **602** transmits beam of coherent light **620** through scanning mirror **610**. Beam of coherent light **620** is directed by scanning mirror **608** to the location to be sampled on composite workpiece **624**.

Response **626** to beam of coherent light **620** from surface **622** of composite workpiece **624** is directed by scanning mirror **608** to scanning mirror **610**. Scanning mirror **610** directs response **626** to spectral sensor system **606**. In this illustrative example, response **626** may be scanned across spectral sensor system **606** through movement of scanning mirror **610** to different positions while receiving response **626**.

Spectral sensor system **606** receives the response, separates the response into a number wavelengths, and generates data. Imaging system **600** may then transmit data to an analyzer, such as analyzer **222** of **Figure 2**.

As depicted, imaging system **600** of **Figure 6** changes the location of a composite workpiece to be sampled by adjusting director system **604**. Accordingly, in this illustrative example, after a first location of composite workpiece **624** is sampled, a second location of the composite workpiece is identified. Scanning mirror **608** is adjusted by driving mechanism **612** to a second position. The second position is calculated to direct beam of coherent light **620** from electromagnetic radiation source **602** to the second location on surface **622** of composite workpiece **624**. Likewise, scanning mirror **610** is adjusted to move to different positions by driving mechanism **614** to receive a response from scanning mirror **608** in the second position. In this manner, response **626** to beam of coherent light **620** directed to the second location may be scanned across spectral sensor system **606**. In this illustrative example, different locations on surface **622** of composite workpiece **624** are sampled by the adjusting director system **604**. In this illustrative example, imaging system **600** remains stationary.

However, changing the location of the composite workpiece to be sampled may be accomplished in other ways. For example, in other illustrative examples, rather than adjusting director system **604**, imaging system **600** may be moved. Alternatively, rather than adjusting director system **604** or moving imaging system **600**, composite workpiece **624** may be moved in relation to imaging system **600**. In illustrative examples in which imaging system **600** or composite workpiece **624** are moved in relation to each other, director system **604** need not be comprised of moveable components.

Turning now to **Figure 7**, an illustration of an imaging system is depicted in accordance with an illustrative embodiment. Imaging system **700** is an example of one implementation for imaging system **216** shown in block form in **Figure 2** and **Figure 3**. Imaging system **700** comprises director system **702**, spectral sensor system **704**, and housing **706**.

In this illustrative example, spectral sensor system **704** is located inside of housing **706**. Director system **702** is comprised of scanning mirror **708** and opening **710**. Scanning mirror **708** may be moved to different positions by driving mechanism **712**.

As depicted, imaging system **700** does not include electromagnetic radiation source **713** within housing **706**. Instead, electromagnetic radiation source **713** may be elsewhere in imaging system **700** or part of another system.

In this depicted example, response **714** is received through opening **710** in housing **706**. Response **714** is directed toward spectral sensor system **704** by scanning mirror **708**.

In this illustrative example, response **714** may be directed toward different locations on spectral sensor system **704** through movement of scanning mirror **708** to different positions. Response **714** from a particular location on surface **716** of composite workpiece **718** is a response to electromagnetic radiation **720** being directed to surface **716** of composite workpiece **718**. Response **714** is selected through movement of housing **706**. In particular, the movement of opening **710** over different locations on surface **716** of composite workpiece **718** is used to select the location for which response **714** is received in these illustrative examples.

Turning now to **Figure 8**, an illustration of a spectral sensor system is depicted in accordance with an illustrative embodiment. In this illustrative example,

spectral sensor system **800** is an example of one physical implementation for spectral sensor system **300** shown in block form in **Figure 3**. In this illustrative example, spectral sensor system **800** includes filter **802** and sensor array **804**. Filter **802** takes the form of a wedge filter in these illustrative examples. In one illustrative example, filter **802** may have a range of wavelengths from about 400 nanometers to about 3,600 nanometers.

Filter **802** includes blocking filter **806**, substrate **808**, and spectral disperser **810**. As depicted, substrate **808** is formed on spectral disperser **810**. Blocking filter **806** is formed on substrate **808**.

Blocking filter **806** in filter **802** is configured to reduce out of band electromagnetic radiation that passes through filter **802**. In this illustrative example, blocking filter **806** may reduce electromagnetic radiation that passes through blocking filter **806** that has a wavelength that is outside of a range from about 400 nanometers to about 1,000 nanometers or a wavelength that is outside of a range from about 500 nanometers to about 3,600 nanometers. Of course, other ranges may be used depending on the particular implementation.

In these illustrative examples, blocking filter **806** is comprised of material that may be selected to reduce radiation for particular wavelengths in a spectral region. In other illustrative examples, the material used to form blocking filter **806** may be selected to reduce substantially all of the radiation that is out of band for blocking filter **806**. In these illustrative examples, electromagnetic radiation is out of band for blocking filter **806** when the electromagnetic radiation has a wavelength that is from about 400 nanometers to about 1,000 nanometers.

Substrate **808** may be comprised of material that is selected to be substantially transparent for electromagnetic radiation having a wavelength or wavelengths of interest. In other words, substrate **808** may allow wavelengths of interest to pass while other wavelengths that are not desirable are blocked from passing through substrate **808**. In this illustrative example, wavelengths of interest are wavelengths from about 400 nanometers to about 1,000 nanometers.

Spectral disperser **810** is comprised of layers **812**. Layers **812** include layers having different refractive indexes. In these illustrative examples, layers **812** are tapered in thickness to create wedge shape **814**. In other words, layers **812** are thicker at edge **818** than at edge **820** of spectral disperser **810**. The materials and thickness of

these layers are selected to provide the range of frequencies that may be separated by filter **802**.

In these illustrative examples, length **822** of filter **802** defines the range of frequencies that may be passed by filter **802**. In other words, the wavelength passed through filter **802** is dependent upon the location along length **822** in which electromagnetic radiation passes into filter **802**. In other words, length **822** is a spectral dimension for filter **802**.

In other words, the wavelength passed by filter **802** increases in the direction of arrow **824**. Thus, edge **820** provides a shortest wavelength that may be passed by filter **802** while edge **818** provides a longest wavelength that may be passed by filter **802**.

Length **826** is a spatial dimension for filter **802**. Locations along length **826** correspond to locations on a surface of a composite workpiece in these illustrative examples. In one illustrative example, locations along length **826** may correspond to plurality of locations **522** along width **514** of composite workpiece **506** in **Figure 5**.

Sensor array **804** is comprised of sensors **828**. In these illustrative examples, sensors **828** are arranged in rows and columns. The size of sensors **828** may affect the spectral resolution and spatial resolution for spectral sensor system **800**. In these illustrative examples, sensors **828** are configured to generate signals in response to detecting electromagnetic radiation. These signals may represent amplitude, intensity, or other parameters depending on the particular implementation. These signals form some or all of data **232** in **Figure 2**.

Sensor array **804** may be implemented using different types of sensors. For example, sensors **828** in sensor array **804** may be comprised of digital-charged-coupled-devices, complimentary metal oxide semiconductor devices, indium antimonide (InSb) semiconductor devices, mercury cadmium telluride (HgCdTe) semiconductor devices, or any other type of sensors suitable for detecting electromagnetic radiation.

The illustrations of imaging system **500** in **Figure 5**, imaging system **600** in **Figure 6**, and imaging system **700** in **Figure 7** are not meant to limit the manner in which imaging system **216** may be implemented. For example, other imaging systems also may include a visible light sensor system, a projector, or both in addition to the components illustrated for imaging system **500**, imaging system **600**, and imaging system **700**. As another illustrative example, multiple sources of coherent light may be

present. In other words, one or more additional sources of coherent light may be present in addition to the source emitting coherent light **504** in imaging system **500**.

In another illustrative example, other forms of electromagnetic radiation may be used in addition to or in place of coherent light. For example, electromagnetic radiation may be non-coherent light from arc lamp or a light emitting diode.

Further, the illustration of spectral sensor system **800** in **Figure 8** is not meant to limit the manner in which spectral sensor system **800** may be implemented in imaging system **600** and imaging system **700**. For example, other types of structures may be used in place of or in addition to the wedge shaped filter used for filter **802**. For example, other structures may be selected from at least one of an optical prism, a holographic grating, a conventional grating, and other suitable types of structures.

With reference next to **Figure 9**, an illustration of a two-dimensional image with graphical indicators is depicted in accordance with an illustrative embodiment. As depicted, image **900** is an example of an implementation of image **234** shown in block form in **Figure 2**.

In this illustrative example, image **900** is two-dimensional image **902**. As depicted, two-dimensional image **902** is an image of composite workpiece **904**. Composite workpiece **904** is a composite workpiece for a wing of an aircraft in these illustrative examples.

In this illustrative example, two-dimensional image **902** includes graphical indicators **906**, **908**, **910**, and **912**. These graphical indicators are a set of graphical indicators identifying a set of contaminants on surface **914** of composite workpiece **904**.

In this illustrative example, graphical indicator **906** indicates a presence of an unknown contaminant on surface **914** of composite workpiece **904**. Graphical indicator **908** and graphical indicator **910** indicate a presence of water on surface **914** of composite workpiece **904**. Graphical indicator **912** indicates a presence of a plastic particle on surface **914** of composite workpiece **904**.

With two-dimensional image **902**, an operator may identify contaminants present on surface **914** of composite workpiece **904**. In this manner, these contaminants may be taken into account prior to finishing layup of layers of composite material on composite workpiece **904** and curing composite workpiece **904**. For example, contaminants may be removed from surface **914**. In other illustrative examples, one or more layers may be replaced in composite workpiece **904**.

The different components shown in **Figure 1** and **Figures 4-9** may be combined with components in **Figures 2-4**, used with components in **Figures 2-4**, or a combination of the two. Additionally, some of the components in **Figure 1** and **Figures 4-9** may be illustrative examples of how components shown in block form in **Figures 2-4** can be implemented as physical structures.

With reference now to **Figure 10**, an illustration of a flowchart of a process for inspecting a composite workpiece is depicted in accordance with an illustrative embodiment. In this depicted example, the process illustrated in **Figure 10** may be implemented in inspection environment **200** in **Figure 2** for use in manufacturing environment **100** in **Figure 1**. In these illustrative examples, the process may be used to inspect workpieces such as composite workpiece **206** in **Figure 2**. This process is performed prior to the composite workpiece being cured or particular layers on the composite workpiece being cured.

The process begins by directing electromagnetic radiation to a surface of a composite workpiece (operation **1000**). The electromagnetic radiation may originate from electromagnetic radiation source **218** in **Figure 2**. The process then detects a response to the electromagnetic radiation directed to the surface of the composite workpiece (operation **1002**). The response may be detected and processed in the subsequent operations in this figure by inspection system **202** in **Figure 2**. Next, the response to the electromagnetic radiation directed to the surface of the composite workpiece is separated into a number of wavelengths for each of a number of locations on the surface of the composite workpiece (operation **1004**). The electromagnetic radiation may be separated by imaging system **216** in inspection system **202**. The response may be for more than one location. In these illustrative examples, the response may be along a line or some other area. In one illustrative example, the response may be for plurality of locations **522** at position **520** along length **518** of composite workpiece **506** in **Figure 5**.

Next, the process identifies a set of contaminants on the surface of the composite workpiece from the number of wavelengths for each of the number of locations on the surface of the composite workpiece (operation **1006**). The identification of contaminants in operation **1006** may be performed by analyzer **222** in inspection system **202**. In these illustrative examples, the set of contaminants may be zero contaminants in some cases if none are detected.

A two-dimensional image of the surface of the composite workpiece with a set of graphical indicators indicating the set of contaminants identified from the number of wavelengths for each of the number of locations on the surface of the composite workpiece is generated (operation **1008**). The two-dimensional image may be generated by analyzer **222**. In this illustrative example, each of the contaminants is identified using a graphical indicator. If no contaminants are present, then the set of graphical indicators is an empty set. In these illustrative examples, the two-dimensional image may be generated using data from the wavelengths.

For example, for places where contaminants are not present, the image may use a particular graphical indicator to indicate an absence of contaminants. In other illustrative examples, the graphical indicators may be placed in a visible light image generated of the surface of the composite workpiece. The visible light image may also be generated by imaging system **216** in inspection system **202** in **Figure 2**.

The process then projects the two-dimensional image with the set of graphical indicators onto the surface of the composite workpiece (operation **1010**) with the process terminating thereafter. The projection of the two-dimensional image onto the surface of the workpiece may be performed using imaging system **216** under the control of analyzer **222**.

Turning now to **Figure 11**, an illustration of a flowchart of a process for identifying a set of contaminants from a number of wavelengths is depicted in accordance with an illustrative embodiment. The process illustrated in **Figure 11** is an example of one implementation of operation **1006** in **Figure 10**.

The process begins by selecting a location from the number of locations on the surface of the composite workpiece (operation **1100**). For example, the location may be a location within plurality of locations **522** for composite workpiece **506** in **Figure 5**. In other illustrative examples, the number of locations may be all of the locations across width **514** for all positions along length **518** of composite workpiece **506**.

Data for the location is identified (operation **1102**). This data is data generated from a number of wavelengths for the selected locations. The data may include, for example, a wavelength and a value for the wavelength. This value may be an intensity, an amplitude, or some other suitable value. The data for the location is a signature for that location in these illustrative examples.

The process then compares the signature to a group of signatures in a signature database (operation **1104**). The signature database may be, for example, signature database **240** in **Figure 2**. The signature database includes signatures for known contaminants. Further, the database also may include signatures for known composite materials that should be present in the composite workpiece.

A determination is then made as to whether a contaminant is present in the location based on the comparison of the signature for the location with the signature database (operation **1106**). If a contaminant is present, the process then identifies the contaminant (operation **1108**). This identification may be based on identifying the contaminant as being one in the signature database. In some cases, if the contaminant does not match a signature for known contaminants in the signature database and also does not match a signature for composite materials that should be present, the contaminant is identified as an unknown contaminant.

Thereafter, a determination is made as to whether an additional unprocessed location is present in the number of locations on the surface of the composite workpiece (operation **1110**). If an additional unprocessed location is present, the process returns to operation **1100**. Otherwise, the process terminates.

With reference again to operation **1106**, if a contaminant is not present, the location is identified as having an absence of a contaminant (operation **1112**) with the process then proceeding to operation **1110** as described above. In operation **1112**, the identification may include an identification of the material that is present at the location. In this case, the material is one that is expected to be present for the composite workpiece.

Turning now to **Figure 12**, an illustration of a flowchart of a process for generating a two-dimensional image of a surface of a composite workpiece with a set of graphical indicators indicating a set of contaminants is depicted in accordance with an illustrative embodiment. The process illustrated in **Figure 12** is an example of one implementation of operation **1008** in **Figure 10**.

The process begins by selecting a contaminant from a set of contaminants for processing (operation **1200**). The process identifies the contaminant (operation **1202**). The identification is one generated in operation **1108** in **Figure 11**.

Based on the identification of the contaminant, the process selects a graphical indicator for the contaminant (operation **1204**). The graphical indicator may

take various forms. For example, the graphical indicator may be selected from at least one of color, an icon, text, cross-hatching, and other suitable types of graphical indicators. The process then identifies a location for the graphical indicator in the two-dimensional image (operation **1206**). The location in the two-dimensional image is a location that corresponds to the location of the contaminant on the surface of the workpiece. The process then places the graphical indicator in the two-dimensional image at the identified location (operation **1208**).

Next, a determination is made as to whether an additional unprocessed contaminant is present in the set of contaminants identified (operation **1210**). If an additional unprocessed contaminant is present for processing, the process returns to operation **1200**.

Otherwise, the process terminates with the two-dimensional image being ready for analysis by an operator. The operator may view the image on a display device. In some illustrative examples, the two-dimensional image may be projected onto the surface of the workpiece. The projection of the two-dimensional image is made such that the graphical indicators are located in locations where the contaminants are actually present on the surface of the workpiece. Further, the shape and size of the graphical indicators may be selected such that they have the same size and shape of the contaminants on the surface of the workpiece.

Turning now to **Figure 13**, an illustration of a flowchart of a process for inspecting a composite workpiece is depicted in accordance with an illustrative embodiment. In this illustrative example, the process in **Figure 13** may be implemented in inspection environment **200** in **Figure 2** for use within manufacturing environment **100** in **Figure 1**. In particular, the different operations may be implemented in inspection system **202** in **Figure 2**.

The process begins by identifying an area of the composite workpiece for inspection (operation **1300**). The area may be a portion or all of the composite workpiece depending on the particular implementation.

For example, for reducing time needed for inspections, an area selected may be one that has had an undesired number of inconsistencies during previous manufacturing of the composite structure. This identification may be made from statistical information from manufacturing the same composite structure over time. In

other illustrative examples, the area may be selected as one having geometries that are sufficiently complex that inconsistencies may be expected to be higher than desired.

The process then identifies a signature database for use in analyzing data generated from separating a response into wavelengths (operation **1302**). The process then directs electromagnetic radiation onto the selected inspection area (operation **1304**).

Thereafter, the process generates data from wavelengths separated in response to the electromagnetic radiation (operation **1306**). The process generates a visible light image of a selected location using a visible light sensor system (operation **1308**).

The process then identifies materials present for the composite workpiece using the data generated from the wavelengths separated from the response using the signature database (operation **1310**). Operation **1310** identifies contaminants as well as materials expected to be present for the composite workpiece.

The process then identifies locations of the materials (operation **1312**). The locations may be coordinates for the composite workpiece. Of course, any coordinate system may be used. In these illustrative examples, the coordinate system may be a two-dimensional or three-dimensional coordinate system in which an origin is present somewhere on the composite workpiece.

The process then places graphical indicators for any contaminants found on the visible light image (operation **1314**). The process then determines whether a contaminant is present (operation **1316**). If a contaminant is present, then an alert is generated (operation **1318**). Thereafter, the contaminant may be removed (operation **1319**). A determination is then made as to whether the composite workpiece is completed and ready for curing (operation **1320**). If the composite workpiece is completed, the process then cures the composite workpiece (operation **1322**) with the process terminating thereafter.

With reference again to operation **1316**, if contaminants are not present, the process also proceeds to operation **1320**. With reference again to operation **1320**, if the composite workpiece is not completed, then a number of composite layers are laid up on the composite workpiece (operation **1324**). The process then returns to operation **1300**).

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

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

Turning now to **Figure 14**, an illustration of a data processing system is depicted in accordance with an illustrative embodiment. Data processing system **1400** may be used to implement computer system **238** in **Figure 2**. In this illustrative example, data processing system **1400** includes communications framework **1402**, which provides communications between processor unit **1404**, memory **1406**, persistent storage **1408**, communications unit **1410**, input/output (I/O) unit **1412**, and display **1414**. In this example, communication framework may take the form of a bus system.

Processor unit **1404** serves to execute instructions for software that may be loaded into memory **1406**. Processor unit **1404** may be a number of processors, a multi-processor core, or some other type of processor, depending on the particular implementation.

Memory **1406** and persistent storage **1408** are examples of storage devices **1416**. 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 **1416** may also be referred to as computer readable storage devices in these illustrative examples. Memory **1406**, in these examples, may be, for example, a random access memory or any other suitable volatile or non-volatile storage

device. Persistent storage **1408** may take various forms, depending on the particular implementation.

For example, persistent storage **1408** may contain one or more components or devices. For example, persistent storage **1408** 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 **1408** also may be removable. For example, a removable hard drive may be used for persistent storage **1408**.

Communications unit **1410**, in these illustrative examples, provides for communications with other data processing systems or devices. In these illustrative examples, communications unit **1410** is a network interface card.

Input/output unit **1412** allows for input and output of data with other devices that may be connected to data processing system **1400**. For example, input/output unit **1412** may provide a connection for user input through a keyboard, a mouse, and/or some other suitable input device. Further, input/output unit **1412** may send output to a printer. Display **1414** provides a mechanism to display information to a user.

Instructions for the operating system, applications, and/or programs may be located in storage devices **1416**, which are in communication with processor unit **1404** through communications framework **1402**. The processes of the different embodiments may be performed by processor unit **1404** using computer-implemented instructions, which may be located in a memory, such as memory **1406**.

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 **1404**. The program code in the different embodiments may be embodied on different physical or computer readable storage media, such as memory **1406** or persistent storage **1408**.

Program code **1418** is located in a functional form on computer readable media **1420** that is selectively removable and may be loaded onto or transferred to data processing system **1400** for execution by processor unit **1404**. Program code **1418** and computer readable media **1420** form computer program product **1422** in these illustrative examples. In one example, computer readable media **1420** may be computer readable storage media **1424** or computer readable signal media **1426**.

In these illustrative examples, computer readable storage media **1424** is a physical or tangible storage device used to store program code **1418** rather than a medium that propagates or transmits program code **1418**.

Alternatively, program code **1418** may be transferred to data processing system **1400** using computer readable signal media **1426**. Computer readable signal media **1426** may be, for example, a propagated data signal containing program code **1418**. For example, computer readable signal media **1426** may be an electromagnetic signal, an optical signal, and/or any other suitable type of signal. These signals may be transmitted over communications links, such as wireless communications links, optical fiber cable, coaxial cable, a wire, and/or any other suitable type of communications link.

The different components illustrated for data processing system **1400** are not meant to provide architectural limitations to the manner in which different embodiments may be implemented. The different illustrative embodiments may be implemented in a data processing system including components in addition to and/or in place of those illustrated for data processing system **1400**. Other components shown in **Figure 14** 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 **1418**.

Illustrative embodiments of the disclosure may be described in the context of aircraft manufacturing and service method **1500** as shown in **Figure 15** and aircraft **1600** as shown in **Figure 16**. Turning first to **Figure 15**, an illustration of an aircraft manufacturing and service method is depicted in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **1500** may include specification and design **1502** of aircraft **1600** in **Figure 16** and material procurement **1504**.

During production, component and subassembly manufacturing **1506** and system integration **1508** of aircraft **1600** in **Figure 16** takes place. Thereafter, aircraft **1600** in **Figure 16** may go through certification and delivery **1510** in order to be placed in service **1512**. While in service **1512** by a customer, aircraft **1600** in **Figure 16** is scheduled for routine maintenance and service **1514**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of aircraft manufacturing and service method **1500** may be performed or carried out by a system integrator, a third party, and/or an

operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

With reference now to **Figure 16**, an illustration of an aircraft is depicted in which an illustrative embodiment may be implemented. In this example, aircraft **1600** is produced by aircraft manufacturing and service method **1500** in **Figure 15** and may include airframe **1602** with plurality of systems **1604** and interior **1606**. Examples of systems **1604** include one or more of propulsion system **1608**, electrical system **1610**, hydraulic system **1612**, and environmental system **1614**. Any number of other systems may be included. Although an aerospace example is shown, different illustrative embodiments may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **1500** in **Figure 15**.

In the illustrative examples, a method and apparatus may be implemented in inspection environment **200** to inspect composite workpieces formed during components and subassembly manufacturing **1506**. As another illustrative example, a method and apparatus in accordance with an illustrative embodiment also may be implemented during maintenance and service **1514** for composite workpieces being processed for forming composite structures used in replacing or upgrading composite structures in aircraft **1600**. The use of a number of the different illustrative embodiments may substantially expedite the assembly of and/or reduce the cost of aircraft **1600**.

Thus, the illustrative embodiments provide a method and apparatus for inspecting a composite workpiece. Further, the illustrative embodiments also may be used to inspect the surface of a tool on which materials may be laid up to form a composite workpiece. The illustrative embodiments perform inspections to identify contaminants on the surface of a layer of composite material prior to the composite workpiece being cured. In this manner, contaminants or areas containing the contaminants may be removed. As a result, the number of inconsistencies that may be present in a composite structure may be reduced. With the reduction of inconsistencies, the amount of rework or remanufacturing of composite structures also may be reduced.

Further, contaminants may be identified on areas that are not included in the final composite structure. These areas may be, for example, areas of the composite workpiece or layers of composite material for use in forming the composite workpiece. For example, contaminants may be identified on an area of the composite workpiece that will not be used or in an area that will be discarded. In other words, parts of the composite workpiece that will be discarded during manufacturing of a composite structure may not be inspected for contaminants. The presence of contaminants in these types of areas may not be of concern in forming the composite workpiece.

Additionally, the inspection field may be set such that only areas used in the final composite structure may be inspected. Thus, the time required for the inspection and identification of contaminants on a composite workpiece may be reduced.

The different illustrative embodiments also may be used to perform quality control types of inspections for the incoming composite material at the receiving dock. For example, performing an inspection of composite materials prior to the composite materials being placed onto tools or otherwise processed into a composite workpiece could identify contaminants on the composite material prior to using the composite material in the work stream. Additionally, the different illustrative embodiments also may be used to identify inconsistencies in the composite materials that are to be used to form a workpiece. As used herein, an "inconsistency", when used with reference to a composite material for use in forming a composite workpiece, may include a contaminant, disbonding in the composite material, delamination in the composite material, or other undesired conditions in the composite map. As a result, time and money may be saved by discovering a contaminant at this stage versus discovering the contaminant later during the manufacturing process.

In these illustrative examples, the inconsistency in the composite material for use when forming a workpiece may be on the surface of the composite material or located within the interior of the composite material. The image generated from the response to the electromagnetic radiation may include graphical indicators that indicate these inconsistencies. The graphical indicators may be selected to indicate the type of inconsistency that has been detected.

The illustrative embodiments provide a method and apparatus that allows for a reduction in the amount of time needed to manufacture parts for composite structures. As a result, the cost, time, or both the cost and the time for manufacturing a platform, such as an aircraft, may be reduced.

The description of the different illustrative 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 illustrative embodiments may provide different features as compared to other illustrative 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.

CLAIMS:

What is claimed is:

1. A method for inspecting a composite workpiece, the method comprising:

separating a response to electromagnetic radiation directed to a surface of the composite workpiece into a number of wavelengths for each of a number of locations on the surface of the composite workpiece;

identifying a set of contaminants not visible to a naked eye on the surface of the composite workpiece from the number of wavelengths for the each of the number of locations; and

generating a two-dimensional image of the surface of the composite workpiece with a set of graphical indicators indicating the set of contaminants not visible to the naked eye identified from the number of wavelengths for the each of the number of locations on the surface of the composite workpiece.

2. The method of claim 1, wherein identifying the set of contaminants not visible to the naked eye on the surface of the composite workpiece from the number of wavelengths for the each of the number of locations comprises:

identifying the set of contaminants not visible to the naked eye based on a comparison of the number of wavelengths for the each of the number of locations on the surface of the composite workpiece to a database of wavelengths for known contaminants.

3. The method of claim 1 further comprising:

projecting the two-dimensional image with the set of graphical indicators onto the surface of the composite workpiece.

4. The method of claim 1, wherein generating the two-dimensional image of the surface of the composite workpiece with the set of graphical indicators indicating the set of contaminants not visible to the naked eye identified from the number of wavelengths for the each of the number of locations on the surface of the composite workpiece comprises:

generating the two-dimensional image of the surface of the composite workpiece with a visible light sensor system; and

including the set of graphical indicators indicating the set of contaminants not visible to the naked eye identified from the number of wavelengths for the each of the number of locations on

the surface of the composite workpiece in the two-dimensional image in locations corresponding to the number of locations.

5. The method of claim 1, wherein the separating, identifying, and generating steps are performed when a number of layers of composite material are laid up for the composite workpiece.

6. The method of claim 5, wherein the separating, identifying, and generating steps are performed each time the number of layers of the composite material are laid up for the composite workpiece prior to curing the number of layers of composite material.

7. The method of claim 1, wherein the separating, identifying, and generating steps are performed prior to curing the composite workpiece.

8. The method of claim 1, wherein separating the response to the electromagnetic radiation directed to the surface of the composite workpiece into the number of wavelengths for the each of the number of locations on the surface of the composite workpiece comprises:

scanning the response to the electromagnetic radiation across a filter, wherein the filter is configured to separate the response into the number of wavelengths and the filter is selected from the group consisting of an optical prism, a holographic grating, a conventional grating, and a wedge filter.

9. The method of claim 8, wherein the filter is the wedge filter and further comprises a length defining frequencies configured to be passed by the wedge filter, wherein the frequencies increase in a direction along the length.

10. The method of claim 1, wherein the electromagnetic radiation is generated by at least one of a halogen light system, a light emitting diode system, a xenon arc lamp system, a laser diode system, and a quartz lamp system.

11. The method of claim 1, wherein the composite workpiece forms a part for a platform selected from one of an aquatic-based structure, a space-based structure, a surface ship, a tank, a train, a spacecraft, a space station, a satellite, a submarine, an automobile, a power plant, a bridge, a dam, a manufacturing facility, and a building.

12. A method for inspecting a tool for laying up layers of composite material, the method comprising:

separating a response to electromagnetic radiation directed to a surface of the tool into a number of wavelengths for each of a number of locations on the surface of the tool prior to laying up the layers of composite material on the surface of the tool;

identifying a set of contaminants from the number of wavelengths for the each of the number of locations on the surface of the tool; and

generating a two-dimensional image of the surface of the tool with a set of graphical indicators indicating the set of contaminants identified from the number of wavelengths for the each of the number of locations on the surface of the tool.

13. A method for inspecting a composite material, the method comprising:

separating a response to infrared electromagnetic radiation directed to a surface of the composite material into a number of infrared wavelengths for each of a number of locations on the surface of the composite material;

identifying a set of inconsistencies for the composite material from the number of infrared wavelengths for the each of the number of locations; and

generating a two-dimensional image of the composite material with a set of graphical indicators indicating the set of inconsistencies identified from the number of infrared wavelengths for the each of the number of locations on the surface of the composite material.

14. The method of claim 13, wherein the set of inconsistencies comprises inconsistencies selected from the group consisting of voids and a porosity.

15. An apparatus comprising:

a spectral sensor system configured to separate a response to electromagnetic radiation directed at a surface of a composite workpiece into a number of wavelengths comprising wavelengths outside of a visible light spectrum and generate data from the number of wavelengths of the electromagnetic radiation; and

an analyzer configured to cause the spectral sensor system to generate the data from the response after a number of layers of composite material have been laid up for the composite workpiece and prior to the number of layers of composite material being cured, and to generate a two-dimensional image of the surface of the composite workpiece with a set of graphical indicators indicating a set of contaminants identified from the number of wavelengths for each of a number of locations on the surface of the composite workpiece.

16. The apparatus of claim 15 further comprising:

a visible light sensor system configured to generate a visible light image of the surface of the composite workpiece, and wherein the analyzer is configured to include the set of graphical indicators indicating the set of contaminants identified from the number of wavelengths for the each of the number of locations on the surface of the composite workpiece in the visible light image in locations corresponding to the number of locations to form the two-dimensional image of the surface of the composite workpiece with the set of graphical indicators indicating the set of contaminants identified from the number of wavelengths for the each of the number of locations on the surface of the composite workpiece.

17. The apparatus of claim 15, wherein the spectral sensor system comprises:

a filter configured to separate the response to the electromagnetic radiation directed at the surface of the composite workpiece into the number of wavelengths comprising the wavelengths outside of the visible light spectrum;

a sensor array comprising sensors configured to generate the data from the number of wavelengths comprising the wavelengths outside of the visible light spectrum of the electromagnetic radiation separated in the response by the filter, wherein the sensors are selected from the group consisting of digital-charged-coupled-devices, complimentary metal oxide semiconductor devices, indium antimonide (InSb) semiconductor devices, and mercury cadmium telluride (HgCdTe) semiconductor devices; and

wherein the number of wavelengths comprises a continuous range of wavelengths.

18. The apparatus of claim 17 further comprising:

a director system comprising a moveable mirror system configured to cause the response to the electromagnetic radiation to be scanned across the filter; and

an electromagnetic radiation source configured to generate the electromagnetic radiation and to pass coherent light through the moveable mirror system toward the surface of the composite workpiece.

19. The apparatus of claim 15, wherein the set of contaminants identified from the number of wavelengths for the each of the number of locations on the surface of the composite workpiece comprises contaminants selected from the group consisting of liquids, moisture, and plastic particles.

20. The apparatus of claim 15, wherein the analyzer is further configured to identify the set of contaminants by comparing the data to a signature database, wherein a signature in the signature database comprises an intensity for a wavelength in the number of wavelengths that is unique to a contaminant in the set of contaminants and wherein the data comprises at least one of intensities for the number of wavelengths, amplitudes for the number of wavelengths, and the wavelengths.