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(71) Applicant: EMPIRE TECHNOLOGY DEVELOPMENT LLC [US/US]; 2711 Centerville Road, Suite 400, Wilmington, DE 19808 (US).

(72) Inventor: MAXWELL, Ian, Andrew; Unit 1, 23 Sir Thomas Mitchell Rd, Bondi Beach, NSW 2026 (AU).

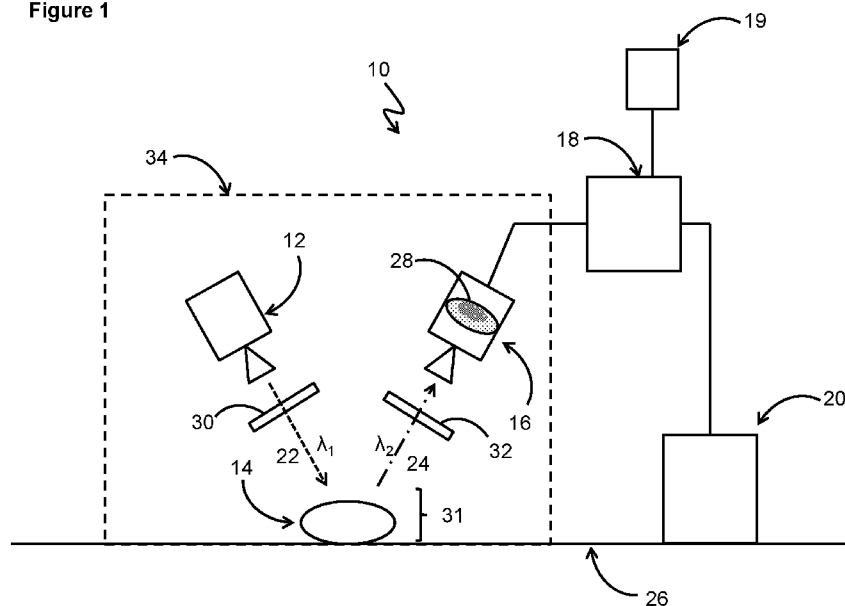
(74) Agent: ISRAELSEN, R., Burns et al.; Maschoff Brennan, 1389 Center Drive, Suite 300, Park City, UT 84098 (US).

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(54) Title: FOOD INSPECTION SYSTEMS AND METHODS

Figure 1



(57) Abstract: A food product inspection system includes a radiation source that emits high power electromagnetic radiation having a wavelength suitable to illuminate a food product and to generate a photoluminescence response therefrom. An imaging sensor detects the photoluminescence response and generates a photoluminescence image of the food product. A quality detection processor analyzes the photoluminescence images to detect food quality properties of the food product. A sorting system for sorts food products based on a spatial position of the food product in dependence on the detected food quality properties. The system may effectively and efficiently determine the quality of the food product by identifying, for example defective food, thereby reducing labor costs associated with inspecting food products. The use of a processor to process the photoluminescence image allows the use of calibration standards to ensure that food products after inspection all have the same characteristics.

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Food Inspection Systems and Methods

This disclosure relates generally to systems that are used to inspect food products, for example for freshness and quality.

Background

5 Food products such as fruits and vegetables are generally inspected to remove defective food. Defects may be aesthetic such as blemishes in the surface of the food, or may be due to more serious issues such as contamination due to insects. Depending on the use of the food product, the defects may or may not be important. For example, food products that are used by canneries typically are not typically concerned with aesthetic defects. However, food such
10 as fruit that is to be sold based on appearance may regard blemishes to be an important consideration during inspection. Therefore, the type of food and its use is an important factor when inspecting food. Food products can be inspected at the time of harvest, or at processing plants, such as depots that distribute food products.

One way to inspect food is by simply visual inspection, usually by unskilled labour.
15 However, the use of unskilled labour is not without problems. People's perception of what is considered a blemish varies and this can lead to variability in the quality of a bulk quantity of food after inspection. This variability can also arise even when guidelines are in place to indicate to the unskilled labour what is and is not defective food. Further, visual inspection generally cannot assess the quality of the food under the surface. For example, the presence
20 of fruit fly and other similar insects underneath the skin of fruit is not always easily detected for fruit that is otherwise blemish-free. The cost of labour can also prohibit thorough inspection protocols, since thorough inspection may lead to excessive costs or slow inspection times.

Accordingly, there may be a need to provide a more efficient and reliable way to
25 inspect food products.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

Summary

30 A first aspect provides a food product inspection system, comprising: at least one radiation source configured to emit high power electromagnetic radiation where the wavelength of the high power electromagnetic radiation is suitable to illuminate a food product at a spatial position within the food product inspection system and generate a photoluminescence response from the food product; at least one imaging sensor configured to

detect the photoluminescence response from the food product and generate one or more photoluminescence images of the food product; at least one quality detection processor configured to analyse the one or more photoluminescence images of the food product to detect quality properties of the food product related to food quality; and at least one sorting system for sorting food products using the spatial position of the food product in dependence on the quality properties of the food product..

The system may help to more accurately and efficiently determine the quality of the food product, for example defective food, and to help reduce labour costs associated with inspecting food products. The use of a processor to process the photoluminescence image may also allow the use of calibration(s) standards to ensure that food products after inspection all have the same characteristics. The system may be adapted to inspect food from small scale inspection operations, for example small farms that harvest fruit and vegetables, to large scale inspection operations, for example depots that inspect large quantities of food on behalf of producers.

The food product may be of the group including: fruit, vegetables, seafood, meat, dairy products and other processed food products. Further, since the system inspects the food product by generating a photoluminescence response, the system may be non-destructive. Imaging sensors may also allow the inspection system to inspect more than 1, 5, 10, 20, 30, 40, 50 or 100+ individual food products per minute. The system may be configured to be retrofitted to existing food inspection apparatus and systems.

In an embodiment, the high power radiation comprises at least 1, 2, 3, 4 or 5 Watts of optical power. The power may be greater than 10 Watts of optical power. Increasing the power of the radiation may help to improve the sensitivity by increasing the signal to noise ratio. In an embodiment, the system comprises a food selection processor for selecting food products having quality properties above a predefined threshold. In an embodiment, the high power radiation is within a predefined wavelength range. In an embodiment, the predefined wavelength range is determined by the emission of the radiation source. In an embodiment, the predefined wavelength range is determined by radiation cut-off optical filters placed in front of the radiation source.

In an embodiment, the predefined wavelength range has different wavelengths from the wavelength range of the photoluminescence response from the food product. In an embodiment, the imaging sensor is a multi-pixel CCD or CMOS camera array sensor. In an embodiment, the multi-pixel CCD or CMOS camera array sensor is selected from the group including: a 2D sensor array, a Time Domain Integration sensor or a single pixel array sensor.

In an embodiment, sensor cut-off optical filters are placed in front of the imaging sensor optics to optimise the wavelength band detected by the imaging sensor. This may help to improve the signal to noise.

In an embodiment, the radiation source is selected from the group including: LED array, halogen flash light, deuterium light sources, arc lamp sources, quartz tungsten halogen sources, lasers, and Xenon flash-lamps. In an embodiment, the radiation source is a high power LED array configured to provide the high power electromagnetic radiation in the form of steady state illumination. In an embodiment, a high power LED array provides the high power electromagnetic radiation in the form of pulsed illumination. In an embodiment, the high power LED array provides pulses at a frequency of at least 1 Hz. The frequency may be greater than 1, 100, 1k, 10k, 100k, 1M, 10M or 50MHz.

In an embodiment, the signs of aging of the food product is related to an average intensity of the photoluminescence response of the food product. In an embodiment, the signs of aging of the food product is related to an average intensity of the photoluminescence response of the food product. In an embodiment, the signs of aging of the food product is detected by a pre-calibrated function of the average intensity of the photoluminescence response of the food product measured at two or more wavelength ranges. In this way, the use of pre-calibrated functions may help to ensure that the food product is consistently inspected so that any results in a quantity of food product can have the same characteristics i.e. little variation in the quality of the food. In an embodiment, the two or more wavelength ranges are the result of two or more illumination wavelength ranges. In an embodiment, the two or more wavelength ranges are the result of two or more photoluminescence detection wavelength ranges.

In an embodiment, processing the photoluminescence response comprises detecting site-specific defects in food products. In an embodiment, the site-specific defects in food products are detected using information associated with the shape of the site-specific defect and where the site-specific defect has different photoluminescence intensity to the surrounding regions of the food product.

In an embodiment, the system further comprises a transport system for moving food products into the spatial position, wherein the transport system is configured to move the food product out of the spatial position after: the application of high power radiation, the imaging sensor has captured photoluminescence images of the food product, and the processor has detected the quality properties of the food product from the photoluminescence images. The transport system may be a conveyor belt or conveyor system.

In an embodiment, the transport system comprises a robotic arm, the robotic arm configured to remove food product having quality properties below a predefined threshold. In an embodiment, the system comprises a high power LED spot indicator to illuminate food products having quality properties below a predefined threshold.

5 In an embodiment, the system further comprises a memory unit for storing photoluminescence images associated with the age of, or defects in food products, a system for calibrating the relationship between the stored photoluminescence images and the age of, or defects in food products, and then a processor that compares the detected photoluminescence response with the calibrated relationship to guide decision making for
10 sorting or rejecting of food product samples in production.

Another aspect provides a method for inspecting a food product, the method comprising the steps of: applying high power electromagnetic radiation from a radiation source so that a wavelength of the high power electromagnetic radiation illuminates a food product at a spatial position to generate a photoluminescence response from the food product;
15 detecting the photoluminescence response from the food product with at least one imaging sensor to generate one or more photoluminescence images of the food product; processing the one or more photoluminescence images of the food product to detect quality properties of the food product related to food quality; and sorting food products on a production line using the spatial position of the food product as determined by the one or more photoluminescence
20 images combined with the quality properties of the food product.

In an embodiment, the food product is of the group including: fruit, vegetables, seafood, meat, dairy products and other processed food products.

In an embodiment, the method further comprises the step of determining a predefined wavelength range from the emission of the radiation source.

25 In an embodiment, the method further comprises the step of placing one or more sensor cut-off optical filters in front of the imaging sensor optics to optimise the wavelength band detected by the imaging sensor. In an embodiment, the radiation source is a high power LED array that pulses the high power electromagnetic radiation to provide pulsed illumination. In an embodiment, high power LED array is pulsed at a frequency of at least 1
30 Hz.

In an embodiment, the quality properties of the food product is determined by a pre-calibrated function of the average intensity of the photoluminescence response of the food product measured at two or more wavelength ranges. In an embodiment, processing the photoluminescence response comprises detecting site-specific defects in food products.

In an embodiment, the site-specific defects in food products are detected using information associated with the shape of the site-specific defect and where the site-specific defect has different photoluminescence intensity to the surrounding regions of the food product.

5 In an embodiment, the method further comprises the step of moving food products into the spatial position, wherein the food product is moved out of the spatial position after: the application of high power radiation, the imaging sensor has captured photoluminescence images of the food product, and the processor has detected the quality properties of the food product from the photoluminescence images.

10 The time for applying radiation, generating the photoluminescence response, detecting the photoluminescence response to form photoluminescence image, processing the image using processor may be less than 0.001, 0.01, 0.1, 0.5, 1, 2, 3, 4, 5 or 10 seconds.

The terms defective, poor quality and the like are used interchangeably to indicate areas and/or food products that are not acceptable and would not pass inspection. Likewise,
15 the terms non-defective, adequate, acceptable and the like are used interchangeably to indicate areas and/or food products that are acceptable and would pass inspection.

Brief summary of Figures

Embodiments will now be described by way of example only with reference to the accompanying non-limiting Figures, in which:

20 Figure 1 shows an embodiment of a food inspection system;

Figure 2 shows an embodiment of a food inspection system;

Figure 3 shows an embodiment of a photoluminescence image; and

Figure 4 shows an embodiment of sorting system that is associated with the food inspection system.

Detailed description

25 Figure 1 shows a food product inspection system 10. The system 19 has at least one radiation source 12 that is adapted to emitting high power electromagnetic radiation, represented by dashed line 22. The high power electromagnetic radiation 22 is adapted to illuminate a food product 14 and generate a photoluminescence response, as represented by
30 dashed line 24, from the food product 14. At least one imaging sensor 16 is configured to detect the photoluminescence response 24 from the food product 14 and generate one or more photoluminescence images, represented by image 28, of the food product 14. At least one processor 18 is configured to process the one or more photoluminescence images 28 of the food product 14 to detect quality properties of the food product related to food quality. The

system 10 also has at least one sorting system 20 for sorting food products on a production line, such as transport system 26 using the spatial position of the food product 14 as determined by the one or more photoluminescence images 28 combined with the quality properties of the food product.

5 The food product 14 can be one or more of fruit, vegetables, seafood, meat, dairy products and other processed food products. Without being bound by theory, chromophores present in the surface or near the surface of the food product 14 adsorbs the radiation 22 to cause one or more electrons in the chromophore to jump from a ground state to an excited energy level. The chromophores may be, for example, chlorophyll present in the surface of
10 the food product 14. Areas of poor quality typically will have different chromophores to chromophores in areas of adequate quality. Therefore, defective areas can give a different photoluminescence response 24 to non-defective areas. This difference can be used to inspect the quality of the food product. The threshold for determining what food is considered defective may be the ratio of defective to non-defective areas.

15 Typically, the electrons are not stable at the excited energy level and fall back to the ground state. The process of an electron moving from an excited energy level to the ground state generally is associated with emission of electromagnetic radiation i.e. photoluminescence response 24. In most cases the wavelength of the photoluminescence response 24 is red-shifted i.e. $\lambda_1 < \lambda_2$ when compared to the radiation 22. By the term red-
20 shifted, it is meant that the λ_2 has a wavelength that has less energy than λ_1 , i.e. has a wavelength that is shifted towards the red-side of the spectrum compared to the λ_1 . The energy difference between the ground state and the excited energy level generally determines the energy requirements of the electromagnetic radiation 22. Generally, the larger the energy difference, the greater the amount of energy is required to cause the electron to jump to the
25 next energy level. The high power radiation 22 in some embodiments comprises at least 1 Watt of optical power, although some embodiments have greater than 10 Watts of optical power. Typically, the more photoresponsive the food product 14 is, the less energy will be required to cause a photoluminescence response.

30 In some embodiments, the radiation 22 can be within a predefined fixed wavelengths range, such as wavelength band or bands. The wavelength of the radiation 22 generally is between UV and far-infra red (IR) i.e. 10nm-1mm. The radiation may comprise all wavelengths between the UV and far-IR range. Alternatively, the radiation 22 may comprise one or more ranges between the UV and far-IR, for example a first band between 10-100 nm, a second band between 400-800 nm, and a third band between 900-1000nm. The

chromophores responsible for the photoluminescence response usually determines the band(s) of required radiation to cause the photoluminescence response. For example, if a food product has two chromophore that adsorb radiation having a wavelength of 600 nm and 950 nm, there may be two bands of radiation 22 of 550-650 nm, and 900-1000 nm. However, to help reduce the noise of the detected signal, the wavelength band(s) λ_1 of radiation 22 should not overlap with the wavelength λ_2 of the wavelength of the photoluminescence response 24.

In an embodiment, the predefined fixed range wavelengths band or bands are determined by the emission of the radiation source. However, this may not be possible in all embodiments, so in some embodiments the predefined fixed range wavelengths band or bands are determined by radiation cut-off optical filters 30 placed in front of the radiation source 12. A broad spectrum radiation source may be used and the cut-off filter 30 may break the broad range spectrum into required band(s).

In an embodiment, the predefined fixed range wavelengths band(s) 22 of the radiation source 12 has different wavelengths from the wavelength band(s) of the photoluminescence response 24 from the food product 14 i.e. $\lambda_1 \neq \lambda_2$. This may help to reduce background noise and improve the signal to noise ratio. However, the system 10 may be configured with a background sensor cut-off filter 32 that blocks the predefined fixed range wavelengths band(s) 22 of the radiation source 12. Use of cut-off filter 32 may help to optimise the wavelength band detected by the imaging sensor, significantly reduce background noise and improve the signal to noise ratio, improve precision and accuracy, and may enable lower cost deployment and faster measurement. In addition, the use of cut-off filter 32 may allow the detection of very low intensity photoluminescent signals. While the embodiment shown in Figure 1 has cut-off filter 32 interacting with the photoluminescence response 24, in some embodiments the cut-off filter 32 may instead be integrated into the processor 18 and/or the sensor 16 so that the filter subtracts any background signal cause from the band(s) 22.

The radiation source 12 may be selected from the group including: LED array, halogen flash light, deuterium light sources, arc lamp sources, quartz tungsten halogen sources, lasers, and Xenon flash-lamps. In an embodiment, the radiation source is a high power LED array configured to provide the high power electromagnetic radiation in the form of steady state illumination. Using high power LED arrays can generate 10 or more Watts of optical power to generate photoluminescence response 24. The benefit of using LED arrays may be that it can generate orders-of-magnitude more photoluminescence response 24 signal which both lowers the cost of the sensor 16 required to detect the photoluminescence response 24, shortens detection periods and also creates new detectable photoluminescence response 24

signals (at different wavelengths) from molecular signatures that in some cases might be below detectable limits at low illumination intensity. Generally, the duration of illumination and detection is short so that damage to the food product 14 will not occur. We note that LED's are generally considered eye-safe due to the lack of optical coherency. They are also now reasonably low cost at many different wavelengths. The high optical power in some embodiments is the primary means by which high levels of background light are dealt with – by having such high power short-bursts of light background light generally becomes much less of an issue especially if the optical system wavelengths and optical filtering technologies are carefully chosen. In addition, Fourier Transform or Lock-In approaches may improve the signal to noise over the background radiation.

The electromagnetic radiation 22 may be provided continuously, or it may be provided as pulsed illumination. If pulsed illumination is used, detection of the photoluminescence response 24 can be performed when the food product 14 is not illuminated by the electromagnetic radiation 22. This may help to improve the signal to noise and detection limits since any background noise from the electromagnetic radiation 22 would not be present. In an embodiment, a high power LED array provides the high power electromagnetic radiation in the form of pulsed illumination. The pulse frequency may be at least 1 Hz, although in some embodiments it is greater than 1 MHz.

Pulsed illumination may also enable the use of two-photon absorption to generate the photoluminescence response 24. Without being bound by theory, two-photon adsorption is the simultaneous absorption of two photons of identical or different frequencies in order to excite a molecule from one state (usually the ground state) to a higher energy electronic state. The energy difference between the involved lower and upper states of the molecule is equal to the sum of the energies of the two photons. An advantage of two-photon adsorption for generating the photoluminescence response 24 is that the electronic radiation 22 can be in the far-IR range, which generally has the ability to penetrate further into the surface of the food product 14. In this way, two-photon adsorption may lead to more accurate detection of food blemishes and/or food that is not acceptable for sale. Further, the wavelength of the photoluminescence response 24 is generally more red-shifted compared to the electromagnetic radiation 22 i.e. $\lambda_1 \ll \lambda_2$, and this can help to improve signal to noise and sensitivity of the system 10 since the larger difference in the energies of λ_1 and λ_2 makes detecting λ_2 from the background easier.

The imaging sensor 16 may be a photo-diode that simply detects single wavelengths. The imaging sensor 16 may comprise more than one photodiode that can detect the intensity

of multiple fixed wavelengths. Alternatively, in an embodiment, the imaging sensor 16 is a multiply-pixel CMOS or CCD camera array sensors. The multi-pixel CCD or CMOS camera array sensor may be selected from the group including: a 2D sensor array, a Time Domain Integration sensor or a single pixel array sensor. In an embodiment, a Time Domain

Integration sensor is used since it can be used to detect the photoluminescence response 24 on objects moving on production line 26. Being able to image moving objects can help to increase the speed at which food 14 is inspected. It may also allow the system 10 to be retro-fitted to existing production lines.

In an embodiment, generation of the photoluminescence image 28 is carried out in an enclosure, as represented by dashed lines 34. The use of an enclosure can help to minimize background noise. Further, the enclosure 34 may help to minimize exposure to harmful radiation, such as UV light to an operator. The enclosure 34 has a first opening to allow food to enter into the enclosure 34, and a second opening to allow food to exit the container 34 (not shown). If food 14 is delivered to the enclosure 34 by means of a conveyor belt, the first and second openings are generally opposite sides of the enclosure 34.

When the system 10 is used with a transport system, such as a conveyor belt, the radiation source 12 and the sensor 16 can span the width of the conveyor. If the size of the radiation source 12 and sensor 16 does not cover the full width of the conveyor, multiple radiation sources 12 and sensors 16 may be placed next to or over another to cover the width of the conveyor. Alternatively, the radiation sources 12 and sensors 16 may be staggered along the direction of travel of the conveyor, with the radiation sources 12 and sensors 16 being positioned relative to one another so that they can inspect the width of the conveyor. Alternatively, the radiation source 12 and/or sensor 16 may span the width of the conveyor. For example, the radiation source 12 may be a strip LED lamp.

While a conveyor system has been described as the transport system, other movement means such as the use of gravity, linear actuators, rollers and similar can be used. The transport system may be in communication with the processor 18 and/or sorting system 20 so that the speed at which food 14 is inspected can be controlled.

Lenses and other similar equipment such as mirrors may be incorporated into the system to ensure the electromagnetic radiation 22 and the photoluminescence response 24 are correctly aligned and optimised to generate the photoluminescence image 28. In the embodiment of Figure 2, lens 36 is positioned to direct electronic radiation 22 from the radiation source 12 onto the food product 14, and lens 40 is positioned to direct the photoluminescence response 24 to the imaging sensor 16. In this way, the optical path length

of the electronic radiation 22 and photoluminescence response 24 is approximately the same as in the embodiment shown in Figure 1, but the system 40 may occupy a smaller or larger footprint. For clarity, various components of the system have been omitted from Figure 2.

There may be a plurality of mirrors and/or lenses to reduce the footprint of system 40. In an embodiment, the optical path length for each of the electronic radiation 22 and photoluminescence response 24 is approximately 500 nm. The mirrors may be electronically or mechanically controlled to ensure correct alignment of the various optical components to generate photoluminescence image 28

Some food products are not flat but are instead shaped so that they protrude above the surface of the production line 26, for example rounded fruits such as apples, melons, oranges and bananas. To help ensure that the whole surface of the food product is scanned, the lenses and other similar equipment associated with the system may be arranged to provide a deep focal plane so as to allow the photoluminescence response 24 to occur over a substantial surface of the food product facing the imaging sensor 16. Having a deep focal plane can help to effectively “flatten” the food product so that the photoluminescence image 28 can be generated for all surfaces exposed by the electronic radiation 22. For example, the imaging sensor 16 may have a variable aperture that can be adjusted to control the depth of the focal plane. The focal plane may be greater than 1, 2, 3, 5, 10 or 20 cm. In the embodiment in Figure 1, the focal plane is represented by region 31. Since region 31 spans the height of the food product 14, the entire upper surface of the food product 14 can be inspected by the system 10. In an embodiment the focal plane is approximately 10 cm. Generally the entire food product is imaged, for example both sides of a fish, or the entire surface of an apple. In these circumstances, the production line 26 may be a conveyor belt that is adapted to rotate and/or turn the food product to ensure that all surface of the food product have been inspected. For example, apples may be arranged on the production line 26 so that they rotate around an axis extending from the stem and through the core. The system 10 may be configured to convert between imaging food products that are substantially flat and rounded.

While Figure 1 describes the use of one radiation source 12 and one imaging sensor 16, some embodiments have two or more radiation sources 12 and two or more imaging sensors 16. For example, each radiation source may emit radiation of a specific wavelength of wavelength band, and each imaging sensor may be configured to detect specific wavelengths of the photoluminescence response 24. In some embodiments, the system and methods described herein may be used to scan an object from two or more directions simultaneously (using two or more image sensors), thus allowing the object (such as fruit or other food

items) to be scanned without rotating the object being scanned. The object can be exposed to the appropriate light source and photoluminescence detected from multiple angles in a three dimensional environment while the object continues on the conveyor system (or other transport system) without modification of the system itself. If the object is to be rejected, the conveyance system may be adapted to remove the rejected object at the time of the scan, subsequent to the scan, or by tracking the object electronically and sorting out rejected items later. Any number of radiation sources 12 and sensors 16 can be used to determine which food item is to be rejected.

To generate the photoluminescence image 28, the photoluminescence response 24 is converted into an intensity 'map' or 'image'. The benefit of using an intensity 'map' or 'image' is that generation of the photoluminescence image 28 may be quick and cheap. When multiple photodiodes are used, each photodiode may detect just the wavelengths that are the most sensitive, for example wavelengths that are associated with chromophores that are present in poor quality regions of food. The intensity of these wavelengths compared to the background can be used to construct the intensity image. Further, image processing can be used to add shape features to algorithms to identify patterns or regions of food products e.g. fruit aging which can add further information and also may be used to improve accuracy and precision of detection.

The intensity of photoluminescence response 24 received and determined by the imaging sensor 16 is used to construct the intensity map. For example, each pixel from a Time Domain Integration sensor is converted into a grey-scale image based on the intensity determined by each pixel. Examples of a photoluminescence image 28 in the form of an intensity image can be seen in Figure 3. In Figure 3A, intensity image 50 has region 42 that corresponds to poor quality regions and region 44 that corresponds to adequate quality regions. This is compared with Figure 3B where the food product is deemed to be of acceptable quality because region 42 does not show on the intensity image 52. An operator may select what intensity is considered acceptable or poor. For example, if a quality threshold of 5% is selected, then no more than 5% of the pixels that comprise the intensity image should display an intensity associated with areas of poor quality. The threshold can be selected by the operator and is generally determined by the type of food product and the use of the food product, for example high quality food for display compared with food products destined for canneries. Instead of a grey-scale image, a black and white image may be constructed, where intensities corresponding to areas of poor quality are shown in black, with

intensities corresponding to areas of adequate quality being shown in white. This may provide a simple visual indicator for an operator as to the quality of the food product.

The processor 18 is in communication with the imaging sensor 16 and is configured to detect quality properties of the food product 14 related to food quality. To detect the quality of the food product 14, the photoluminescence image 28 is assessed by the processor to determine regions representing poor quality e.g. region 42. If the processor determines that the poor quality region is above a threshold value for an identified food product, information can be sent to an operator and/or the sorting system 20 to remove the identified the fruit product from the production line. The photoluminescence image 28 produced by the imaging sensor 16 may be in the form of data packets relating to intensity values for each of the pixels that make up the image 28. The data packets can then be processed by the processor to convert the intensity values to determine the quality of the food product. The processor 18 may additionally control the radiation source 12 and/or imaging sensor 16. For example, if pulsed radiation is used, the processor may instruct imaging sensor 16 to only collect intensity data when the radiation source 12 is not emitting electronic radiation 22. This may help to reduce signal to noise and help to improve sensitivity. Further, the processor 18 may apply algorithms and/or filters to the data packets relating to intensity values that make up image 28 to improve the sensitivity of the system 10. To processor may also integrate image 28 and/or data packets associated with image 28 to provide average intensities of the image 28. When two or more imaging sensors are used, the processor may integrate each image generated by each of the sensors to generate an average image intensity. Integration may allow the system 10 to inspect food products faster and/or with increased sensitivity.

In an embodiment, the processor 18 is in communication with two or more radiation sources and two or more imaging sensors. There may be a radiation processor associated with each of the radiation sources and an imaging processor associated with each of the imaging sensors, and processor 18 may communicate with the radiation processor and imaging processor (not shown). In an embodiment, there are a plurality of processors associated with the radiation source(s) 12, imaging sensor(s) 16, sorting system(s) 20 and/or processor 18.

To determine whether the food product 14 is of adequate quality, the intensities of image 28 are compared to threshold values pre-set by an operator. Therefore, embodiments of the system 10 allow the processor 18 to detect signs of aging in the food product. The threshold values are related to a pre-calibrated function of the average intensity of the photoluminescence response 24 of the food product 14. The pre-calibrated function may be measured at two or more wavelength bands. Regions representative of poor quality may arise

for a number of reasons. For example, bruising may give a different photoluminescence response for over-ripe food compared to under-ripe food. The difference in the photoluminescence response 24 may be related to differences in intensities and/or wavelengths. In this way, the various intensities and wavelengths can be used to determine what type of defect is present in the food product. Therefore, and embodiments allows the photoluminescence response 24 to detect site-specific defects in food products. Depending on the food being inspected, one type of defect may be acceptable e.g. under-ripe food, while other defects are not e.g. bruising. In this way, the system 10 may be able to inspect a variety of food conditions. In an embodiment, the site-specific defects in food products are detected using information associated with the shape of the site-specific defect and where the site-specific defect has different photoluminescence intensity 24 to the surrounding regions of the food product. Areas of poor quality, i.e. defective regions, may also detect features under the surface of the skin, such as holes are bores cause from fruit fly, fruit fly larvae and fruit fly eggs. In this way, radiation sources that are capable of penetrating the surface of the food are used in some embodiments. Changes in the features under the skin may also form from bruising, where the density and consistency of the food is different in the bruised region compared to a non-bruised region. As an example, defects relating to bruising may be detected by the sensor 16 using one band(s) of wavelength(s), and defects relating to the presence of fruit fly may be detected using a second band(s) of wavelength(s).

The system 10 in Figure 1 also comprises a memory unit 19 for storing photoluminescence images associated with the age of, or defects in food products. This may be useful for systems that are required to inspect a variety of food products. Systems that are only inspect one type of food e.g. only apples may not have the memory unit. The memory unit 19 can also have a system for calibrating the relationship between the stored photoluminescence images and the age of, or defects in food products. In this way, quality properties of the food product, such as wavelengths, intensities and/or ratios of wavelengths and/or intensities associated with poor quality fruit may be stored in the memory unit 19. Each photoluminescence image 28 is then compared to the quality properties. Any food product 14 that does not pass the pre-determined quality properties is then indicated as poor quality food. The indicated poor quality food is then identified by the sorting system 20 e.g. the spatial position of the identified poor quality food is transferred to the sorting system 20 and the sorting system 20 then removes the poor quality food. The processor 18, or another processor associated with memory unit 19, may then compare the detected

photoluminescence response with the calibrated relationship to guide decision making for sorting or rejecting of food product samples in production.

In the embodiment in Figure 1, the product line 26 is in the form of a transport system, such as a conveyor system, for moving food products into a measurement area, defined by enclosure 34. If an enclosure is not used, the measurement area is defined by dashed region 34. The transport system 26 moves the food product 14 out of the enclosure area after the application of high power radiation 22, the imaging sensor 16 has captured photoluminescence image 28, and the processor has determined the quality of the food 14 from the photoluminescence image 28. The transport system may continuously move the food product 14 through the enclosure, or may instead move the food product 14 in intervals. If interval movement is used, movement of the food product may coincide with any pulsed illumination and/or image acquisition of the imaging sensor 16. In an embodiment, the transport system arranges the food product 14 into a pre-defined spatial configuration. For example, guides may position the food product to travel along a specific path. The transport system may also have elements such as rollers that help to rotate the food product 14 to ensure that the entire surface of the food product is inspected.

In an embodiment, the system 10 uses steady state inspection where the photoluminescence response 24 is detected while the food 14 is being continuously illuminated by radiation 22. Alternatively, an embodiment uses high-frequency pulsed transient inspection where the radiation source 12 is pulsed at high frequency, such as up to MHz rates, and the photoluminescence response 24 during repetitive 'transient decay' period between each light pulse is detected. Both of these approaches may be cost effective means to inspect the food 14 with high sensitivity so long as the radiation source 12 and imaging sensor 16 cooperate as described above. In an embodiment, the use of steady state or pulsed transient inspection allows fast sample measurement, for example 'on-the-fly' inspection at rate of food movement of 360 mm/s, where the total inspection time per sample is well less than one second including all signal and image processing as well as the algorithms that decide on sample sorting and binning. The time for applying radiation 22, generating the photoluminescence response 24, detecting the photoluminescence response 24 to form photoluminescence image 28, processing the image 28 using processor 18 may be less than 0.001, 0.01, 0.1, 0.5, 1, 2, 3, 4, 5 or 10 seconds.

The sorting system 20 removes any food product that is deemed to be defective i.e. the food product does not pass the pre-set quality threshold. An example of a sorting system is shown in Figure 4. In this embodiment, the sorting system is a robotic arm 60 having

grippers 64 that can grasp the food product 14. Once a defective food product 54 is identified, the grippers 64 grasp the defective food 64 to remove defective food 64 from the transport system 26. To do this, the position of the food product 64 is determined from the photoluminescence image, giving a spatial position of the food product 64. The robotic arm
5 then uses the spatial position to track and remove the defective food product. The transport system moves food products in the direction of arrow 66, therefore the movement of the food products is predictable. Using automated means to remove defective food may help to improve efficiency and reduce labour costs.

In an alternative embodiment (not shown), the sorting system 20 uses a visual
10 indicator to highlight defective food products. For example, the visual indicator may be a light source, such as a LED lamp or laser that can illuminate a spot on food products identified as being poor quality that can be detected by the eye of an operator. Once the operator detects the spot, they can simply remove the defective food from the transport system 26. Another form of sorting system 20 may comprise actuators that can contact food
15 that is considered defective to move it onto a waste bin. The actuator may be a linear actuator that can knock the defective food off a conveyor. Alternatively, the actuator may control a gate that can separate a stream of food moving on a conveyor into a stream of defective food and a stream of desirable food.

In the claims which follow and in the preceding description of the invention, except
20 where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

It will be understood to persons skilled in the art of the invention that many
25 modifications may be made without departing from the spirit and scope of the invention.

Claims:

1. A food product inspection system, comprising:

at least one radiation source configured to emit high power electromagnetic radiation having a wavelength suitable to illuminate a food product at a spatial position within the food product inspection system and generate a photoluminescence response from the food product;

at least one imaging sensor configured to detect the photoluminescence response from the food product and generate one or more photoluminescence images of the food product;

at least one quality detection processor configured to analyse the one or more photoluminescence images of the food product to detect quality properties of the food product related to food quality; and

at least one sorting system for sorting food products using the spatial position of the food product in dependence on the quality properties of the food product.

2. The inspection system according to claim 1, wherein the food product is of the group including: fruit, vegetables, seafood, meat, dairy products and other processed food products.

3. The inspection system according to claims 1 or 2, wherein the high power radiation comprises at least 1 Watt of optical power.

4. The inspection system according to claim 3, wherein the high power radiations comprises greater than 10 Watts of optical power.

5. The inspection system according to any one of claims 1 to 4, further comprising a food selection processor for selecting food products having quality properties above a predefined threshold.

6. The inspection system according to any one of claims 1 to 5, wherein the high power radiation is within a predefined wavelength range.

7. The inspection system according to claim 6, wherein the predefined wavelength range is determined by the emission of the radiation source.

8. The inspection system according to claim 6 or 7, wherein the predefined wavelength range is determined by radiation cut-off optical filters placed in front of the radiation source.
9. The inspection system according to any one of claims 6 to 8, wherein the predefined wavelength range has different wavelengths from the wavelength range of the photoluminescence response from the food product.
10. The inspection system according to any one of claims 1 to 9, wherein the imaging sensor is a multi-pixel CCD or CMOS camera array sensor.
11. The inspection system according to claim 10, wherein the multi-pixel CCD or CMOS camera array sensor is selected from the group including: a 2D sensor array, a Time Domain Integration sensor or a single pixel array sensor.
12. The inspection system according claim 10 or 11, wherein one or more sensor cut-off optical filters are placed in front of the imaging sensor optics to optimise the wavelength band detected by the imaging sensor.
13. The inspection system according to any one of claims 1 to 12, wherein the radiation source is selected from the group including: LED array, halogen flash light, deuterium light sources, arc lamp sources, quartz tungsten halogen sources, lasers, and Xenon flash-lamps.
14. The inspection system according to claim 13, wherein the radiation source is a high power LED array configured to provide the high power electromagnetic radiation in the form of steady state illumination.
15. The inspection system according to claim 13, wherein the radiation source is a high power LED array configured to provide the high power electromagnetic radiation in the form of pulsed illumination.
16. The inspection system according to claim 15, wherein the high power LED array provides pulses at a frequency of at least 1 Hz.
17. The inspection system according to any one of claims 1 to 16, wherein the processor is configured to detect signs of aging in the food product.

18. The inspection system according to claim 17, wherein the signs of aging of the food product is related to an average intensity of the photoluminescence response of the food product.

19. The inspection system according to claim 17, wherein the signs of aging of the food product is detected by a pre-calibrated function of the average intensity of the photoluminescence response of the food product measured at two or more wavelength ranges.

20. The inspection system according to claim 19, wherein the two or more wavelength ranges are the result of two or more illumination wavelength ranges.

21. The inspection system according to claim 19, wherein the two or more wavelength ranges are the result of two or more photoluminescence detection wavelength ranges.

22. The inspection system according to any one of claims 1 to 21, wherein processing the photoluminescence response comprises detecting site-specific defects in food products.

23. The inspection system according to claim 22, wherein the site-specific defects in food products are detected using information associated with the shape of the site-specific defect and where the site-specific defect has different photoluminescence intensity to the surrounding regions of the food product.

24. The inspection system according to any one of claims 1 to 23, further comprising a transport system for moving food products into the spatial position, wherein the transport system is configured to move the food product out of the spatial position after:

the application of high power radiation,

the imaging sensor has captured photoluminescence images of the food product, and

the processor has detected the quality properties of the food product from the photoluminescence images.

25. The inspection system according to any one of claims 1 to 25, wherein the sorting system comprises a robotic arm, the robotic arm configured to remove food product having quality properties below a predefined threshold.

26. The inspection system according to any one of claims 1 to 26, comprising a high power LED spot indicator to illuminate food products having quality properties below a predefined threshold.

27. A method for inspecting a food product, the method comprising the steps of:

5 applying high power electromagnetic radiation from a radiation source so that a wavelength of the high power electromagnetic radiation illuminates a food product at a spatial position to generate a photoluminescence response from the food product;

 detecting the photoluminescence response from the food product with at least one imaging sensor to generate one or more photoluminescence images of the food product;

10 processing the one or more photoluminescence images of the food product to detect quality properties of the food product related to food quality; and

 sorting food products on a production line using the spatial position of the food product as determined by the one or more photoluminescence images combined with the quality properties of the food product.

15 28. The method according to claim 27, wherein the food product is of the group including: fruit, vegetables, seafood, meat, dairy products and other processed food products.

29. The method according to claim 27 or 28, further comprising the step of determining a predefined wavelength range from the emission of the radiation source.

20 30. The method according to any one of claims 28 to 29, further comprising the step of placing one or more sensor cut-off optical filters in front of the imaging sensor optics to optimise the wavelength band detected by the imaging sensor.

31. The method according to any one of claims 27 to 30, wherein the radiation source is a high power LED array that pulses the high power electromagnetic radiation to provide pulsed illumination.

25 32. The method according to claim 31, wherein the high power LED array is pulsed at a frequency of at least 1 Hz.

33. The method according to any one of claims 27 to 32 wherein the quality properties of the food product is determined by a pre-calibrated function of the average intensity of the photoluminescence response of the food product measured at two or more wavelength ranges.

5 34. The method according to any one of claims 27 to 33, wherein processing the photoluminescence response comprises detecting site-specific defects in food products.

35. The inspection system according to claim 34, wherein the site-specific defects in food products are detected using information associated with the shape of the site-specific defect and where the site-specific defect has different photoluminescence intensity to the surrounding regions of the food product.

10 36. The method according to any one of claims 27 to 35, further comprising the step of moving food products into the spatial position, wherein the food product is moved out of the spatial position after:

the application of high power radiation,

15 the imaging sensor has captured photoluminescence images of the food product, and

the processor has detected the quality properties of the food product from the photoluminescence images.

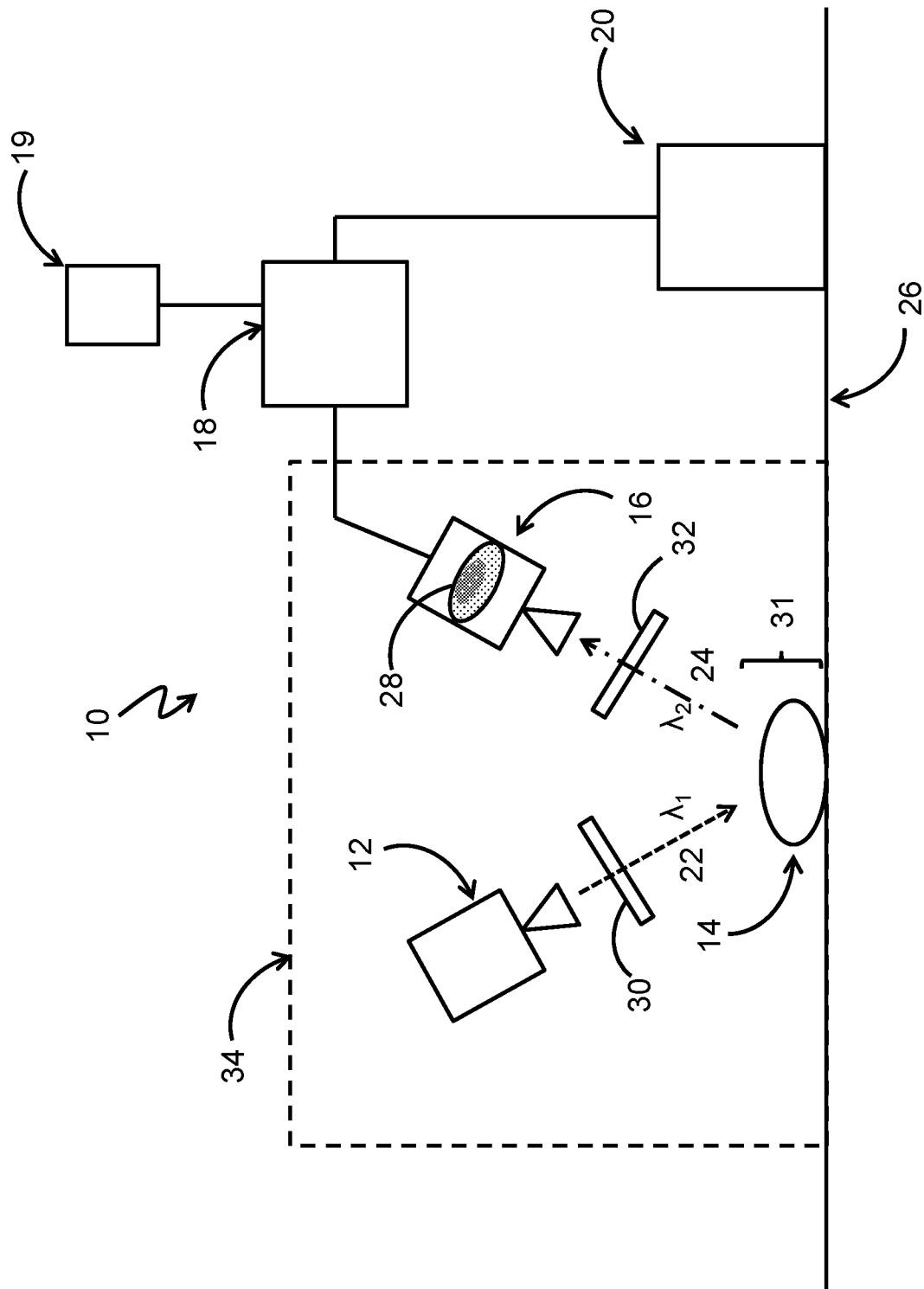


Figure 1

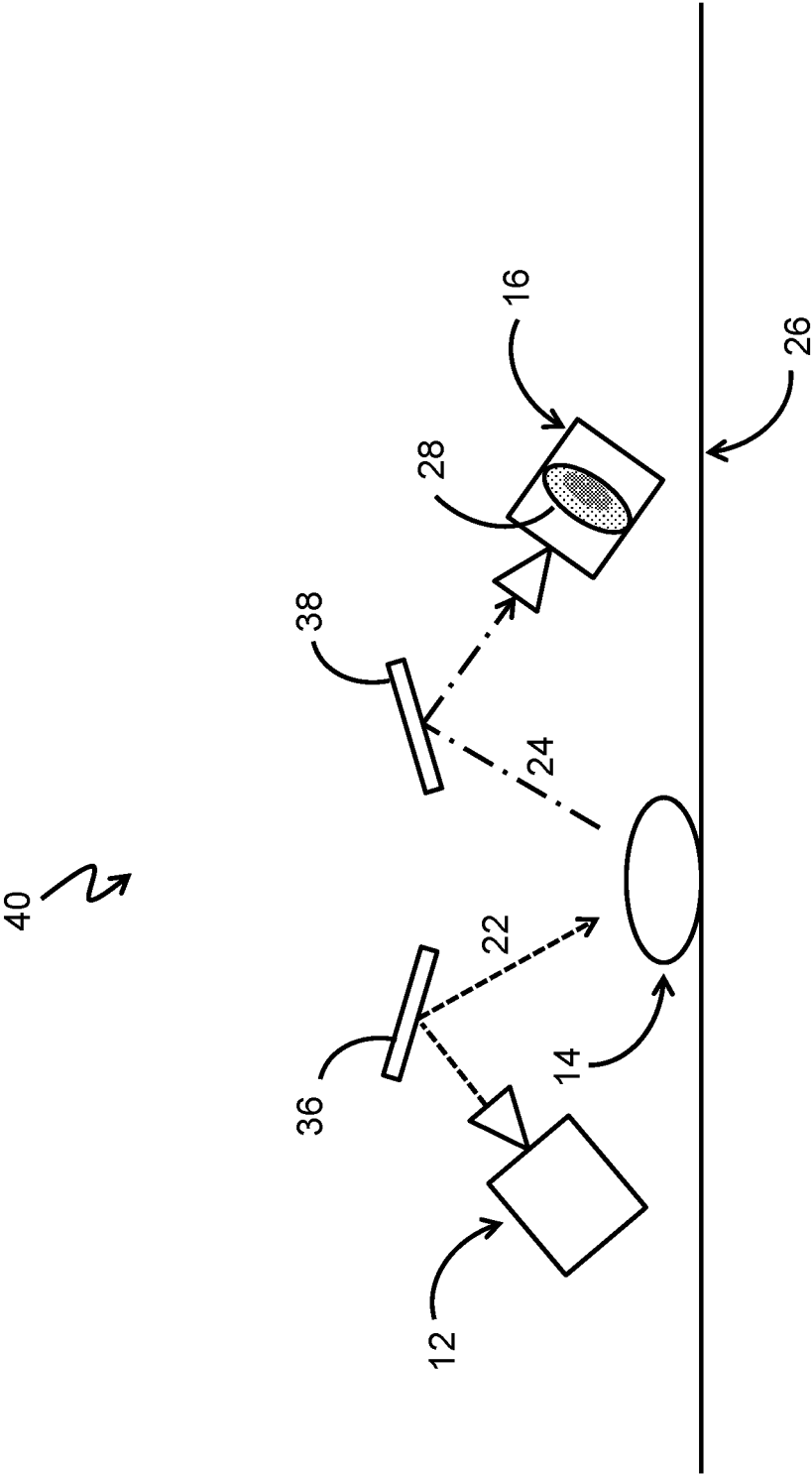


Figure 2

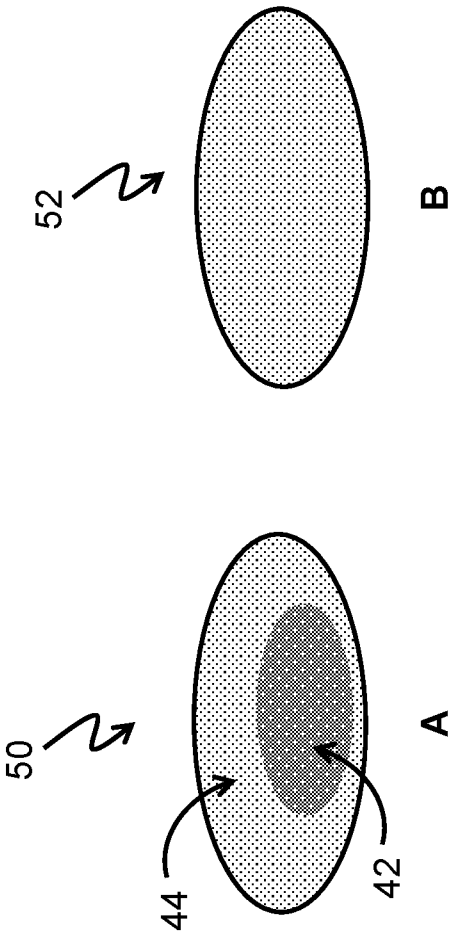


Figure 3

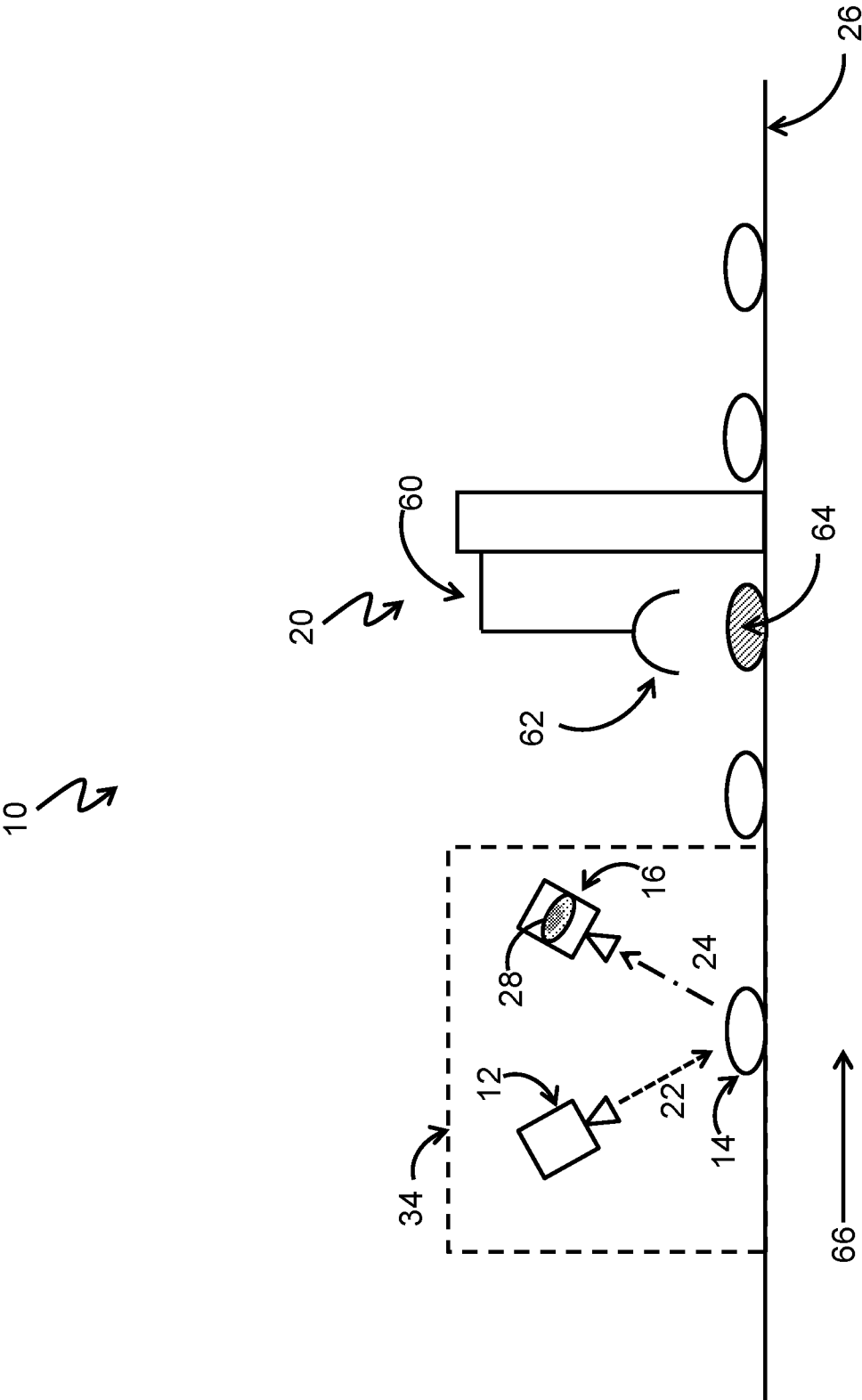


Figure 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/50272

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01N 21/64, B07C 5/344 (2016.01)

CPC - B07C 5/3427, B07C 5/342, B07C 5/34, Y10S 250/91, G01N 21/62, G01N 21/63, G01N 21/64

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G01N21/64, B07C5/344 (2016.01)

CPC - B07C5/3427, B07C5/342, B07C5/34, Y10S250/91, G01N21/62, G01N21/63, G01N21/64

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - G01N21/64, B07C5/344 (2016.01); IPC(8) - B07C5/3427, B07C5/342, B07C5/34, Y10S250/91, G01N21/62, G01N21/63, G01N21/64, G01N21/6402, G01N21/6486 (2016.01) USPC - 426/231, 382/110

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

Patbase; Google Web, Google Patent

Search terms used: photoluminescence fluorescence or phosphorescence food fruit vegetables seafood meat dairy irradiate sort image inspect

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/0093985 A1 (VASILESCU) 19 April 2012 (19.04.2012), para [0006], [0016], [0061], [0063]-[0066], [0073], [0091]	1-4, 27-29
A	Liu, Chao, et al. "On-spot evaluation of maturity stage of fruits based on 655 nm laser-induced photoluminescence of chlorophyll-alpha." 2006 International Symposium on Biophotonics, Nanophotonics and Metamaterials. IEEE, 2006 (2006), entire document	1-4, 27-29
A	US 2012/0021101 A1 (BERGHMANS et al.) 26 January 2012 (26.01.2012), entire document	1-4, 27-29
A	US 4,866,283 A (HILL, JR.) 12 September 1999 (12.09.1999), entire document	1-4, 27-29
A	US 3,216,568 A (JACOB et al.) 09 November 1965 (09.11.1965), entire document	1-4, 27-29

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

* Special categories of cited documents:

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 November 2016

Date of mailing of the international search report

08 DEC 2016

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/50272

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 5-26, 30-36
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.