

METHODS AND APPARATUS FOR CANDLING EGGS
VIA EMBRYO HEARTBEAT DETECTION

FIELD OF THE INVENTION

5 The present invention relates generally to eggs and, more particularly, to methods and apparatus for candling eggs.

BACKGROUND

Discrimination between poultry eggs on the basis of some observable quality is a well-known and long-used practice in the poultry industry. "Candling" is a common name for one such technique, a term which has its roots in the original practice of inspecting an egg using the light from a candle. As is known to those familiar with eggs, although egg shells appear opaque under most lighting conditions, they are in reality somewhat translucent, and when placed in front of direct light, the contents of the egg can be observed.

15 Eggs which are to be hatched to live poultry are typically candled during embryonic development to identify clear, rotted, and dead eggs (collectively referred to herein as "non-live eggs"). Non-live eggs are removed from incubation to increase available incubator space. In many instances it is desirable to introduce a substance, via *in ovo* injection, into a live egg prior to hatch. Injections of various substances into avian eggs are employed in the commercial poultry industry to decrease post-hatch mortality rates or increase the growth rates of the hatched bird. Examples of substances that have been used for, or proposed for, *in ovo* injection include vaccines, antibiotics and vitamins. *In ovo* treatment substances and methods are described in U.S. Pat. No. 4,458,630 to Sharma et al. and U.S. Pat. No. 5,028,421 to Fredericksen et al.

20 *In ovo* injections of substances typically occur by piercing an egg shell to create a hole therethrough (e.g., using a punch, drill, etc.), extending an injection needle through the hole and into the interior of the egg (and in some cases into the avian embryo contained therein), and injecting one or more treatment substances through the needle. An example of an injection device is disclosed in U.S. Pat. No. 4,681,063 to Hebrank. This device positions an egg and an

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injection needle in a fixed relationship to each other, and is designed for the high-speed automated injection of a plurality of eggs. The selection of both the site and time of injection treatment can also impact the effectiveness of the injected substance, as well as the mortality rate of the injected eggs or treated embryos.

- 5 See, for example, U.S. Pat. No. 4,458,630 to Sharma et al., U.S. Pat. No. 4,681,063 to Hebrank, and U.S. Pat. No. 5,158,038 to Sheeks et al.

In commercial poultry production, typically only about 60% to 90% of commercial broiler eggs hatch. Eggs that do not hatch include eggs that were not fertilized, as well as fertilized eggs that have died. Infertile eggs may comprise
10 from about 5% up to about 25% of all eggs in a set. Due to the number of non-live eggs encountered in commercial poultry production, the increasing use of automated methods for *in ovo* injection, and the cost of treatment substances, an automated method for identifying live eggs and selectively injecting only live eggs, is desirable.

15 There are other applications where it is important to be able to identify live and non-live eggs. One of these applications is the cultivation and harvesting of vaccines in live eggs (referred to as "vaccine production eggs"). For example, human flu vaccine production is accomplished by injecting seed virus into a chicken egg at about day eleven of embryonic development (Day-11 egg),
20 allowing the virus to grow for about two days, euthanizing the embryo by cooling the egg, and then harvesting the amniotic fluid from the egg. Typically, eggs are candled before injection of a seed virus to facilitate removal of non-live eggs. Vaccine production eggs may be candled one or more days prior to injection of a seed virus therein. Identification of live eggs in vaccine production is important
25 because it is desirable to prevent seed vaccine from being wasted in non-live eggs, to reduce costs associated with transporting and disposing of non-live eggs, and to reduce the possibility of contamination from non-live eggs.

U.S. Pat. No. 3,616,262 to Coady et al. discloses a conveying apparatus for eggs that includes a candling station and an inoculation station. At the
30 candling station, light is projected through the eggs and assessed by a human

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operator, who marks any eggs considered non-live. Non-live eggs are manually removed before the eggs are conveyed to the inoculating station.

U.S. Patent Nos. 4,955,728 and 4,914,672, both to Hebrank, describe a candling apparatus that uses infrared detectors and the infrared radiation emitted from an egg to distinguish live from infertile eggs. U.S. Patent No. 5,745,228 to Hebrank et al. describes a candling apparatus that includes a photodetector and a photoemitter that are configured to be positioned on opposite sides of an egg. Light is generated in short bursts from each photoemitter and the corresponding photodetector monitors while its corresponding photoemitter is operational. A flat of eggs is continuously "scanned" as it moves through the candling apparatus with each detector-source pair active while at least adjacent, and preferably all other, pairs are quiescent.

Embryo heartbeat (pulse) detection methods are known that can detect live eggs with a high degree of accuracy. For example, U.S. Patent No. 6,860,225 to Hebrank describes candling methods and apparatus wherein cyclical variation in light intensity indicates the existence of an embryo pulse.

U.S. Patent No. 5,173,737 to Mitchell describes a method of determining whether an egg contains a live embryo by directing light into an egg to stimulate embryo movement, and then measuring resulting embryo movement.

Electrical components utilized in embryo heartbeat detection technology can be sensitive to the environment. Unfortunately, egg candling is typically performed in wet, harsh environments that can potentially affect sensitive electronic components.

SUMMARY

In view of the above discussion, egg candling methods and apparatus are provided that can be utilized in the wet, harsh environments of a hatchery and other poultry facilities. According to some embodiments of the present invention, an apparatus for candling eggs includes a waterproof housing having a free end; at least one light source configured to emit visible light from the housing free end and illuminate an egg positioned adjacent to the housing free end; and a

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photodetector at the housing free end that generates an output signal corresponding to intensity of light from the at least one light source leaving the egg. The photodetector is shielded from external light and from direct light from the at least one light source. The at least one light source is disposed within the housing and emits visible light within a range of between 600 nM and 740 nM through a transparent window. The photodetector is disposed within the housing and receives light leaving an egg through the transparent window.

In some embodiments, the at least one light source emits visible light within a range of between 610 nM and 720 nM. In some embodiments, the at least one light source is a light emitting diode (LED) that is configured to emit visible light with a peak intensity at one of the following wavelengths: 625 nM, 639 nM, 660 nM, and 695 nM.

A replaceable bumper is removably secured to the housing free end and is configured to engage an egg in contacting relation therewith. The bumper is configured to shield the photodetector from external light and from direct light from the at least one light source. In some embodiments, a processor is disposed within the housing. The processor processes output signals from the photodetector to identify cyclical variations in light intensity, wherein a cyclical variation in light intensity indicates the existence of an embryo pulse. In some embodiments, the processor may also process output signals from the photodetector to identify non-cyclical variations in light intensity, wherein non-cyclical variations in light intensity indicate embryo movement.

According to other embodiments of the present invention, an apparatus for candling eggs includes a waterproof housing having a free end with a transparent window. A pair of light sources is disposed within the housing and each light source is configured to emit visible light within a range of between 600 nM and 740 nM from the housing free end through the window and illuminate an egg positioned adjacent to the housing free end. A photodetector is positioned within the housing at the free end between the pair of light sources and generates an output signal corresponding to the intensity of light from the light sources leaving the egg. The photodetector is shielded from external light and

from direct light from the light sources via a replaceable bumper removably secured to the housing free end. A processor is disposed within the housing and is configured to process output signals from the photodetector to identify cyclical variations in light intensity, wherein a cyclical variation in light intensity indicates the existence of an embryo pulse. In some embodiments of the present invention, the processor processes output signals from the photodetector to identify non-cyclical variations in light intensity, wherein non-cyclical variations in light intensity indicate embryo movement.

According to further embodiments of the present invention, a method of candling eggs includes positioning an egg adjacent a free end of a detector tool, wherein the detector tool has at least one light source and a photodetector; illuminating the egg with visible light within a range of between 600 nm and 740 nm from the free end via the at least one light source; detecting intensity of light leaving the egg via the photodetector, wherein the photodetector is shielded from external light and from direct light from the at least one light source; generating an output signal that corresponds to detected light intensity; and processing the output signal to identify cyclical and/or non-cyclical variations in light intensity, wherein cyclical variations in light intensity indicate the existence of an embryo pulse, and wherein non-cyclical variations in light intensity indicate embryo movement. In some embodiments, illuminating the egg with light includes illuminating the egg with light from one or more selected portions of the spectrum such as, for example, the visible and/or infrared portions of the spectrum.

According to other embodiments of the present invention, an apparatus for candling eggs includes a waterproof housing having a free end with a transparent window. A photodetector is positioned within the housing at the free end and generates an output signal corresponding to the intensity of light from a light source leaving the egg. The photodetector is shielded from direct light from the light source via a replaceable bumper removably secured to the housing free end. A processor is disposed within the housing and is configured to process output signals from the photodetector to identify cyclical variations in light intensity, wherein a cyclical variation in light intensity indicates the existence of

an embryo pulse. In some embodiments of the present invention, the processor processes output signals from the photodetector to identify non-cyclical variations in light intensity, wherein non-cyclical variations in light intensity indicate embryo movement.

5 According to further embodiments of the present invention, a method of candling eggs includes contacting an egg with a free end of a detector tool, wherein a bumper is secured to the detector tool free end; illuminating the egg with visible light within a range of between 600 nM and 740 nM via a light source; detecting intensity of light leaving the egg via a photodetector within the detector
10 tool, wherein the photodetector is shielded from direct light from the light source via the bumper; generating an output signal that corresponds to detected light intensity; and processing the output signal to identify cyclical and/or non-cyclical variations in light intensity, wherein cyclical variations in light intensity indicate the existence of an embryo pulse, and wherein non-cyclical variations in light
15 intensity indicate embryo movement.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a detector tool, according to some embodiments of the present invention.

20 **Fig. 2a** illustrates the free end of the detector tool of **Fig. 1** with the replaceable bumper removably secured thereto.

Fig. 2b illustrates the free end of the detector tool of **Fig. 1** with the replaceable bumper removed from the free end.

25 **Fig. 3** is a side, cross-sectional view of the free end of the detector tool of **Fig. 1**, illustrating the replaceable bumper in contact with an egg and illustrating the pair of light sources and the photodetector disposed within the housing behind the transparent window.

Fig. 4 is a perspective view of a detector tool, according to other embodiments of the present invention.

30 **Fig. 5a** illustrates the free end of the detector tool of **Fig. 4** with the replaceable bumper removably secured thereto.

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Fig. 5b illustrates the free end of the detector tool of **Fig. 4** with the replaceable bumper removed from the free end.

Fig. 6 is a side, cross-sectional view of the free end of the detector tool of **Fig. 4**, illustrating the replaceable bumper in contact with an egg and illustrating the photodetector disposed within the housing behind the transparent window.

DETAILED DESCRIPTION

The present invention now is described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

Like numbers refer to like elements throughout. In the figures, the thickness of certain lines, layers, components, elements or features may be exaggerated for clarity. Broken lines illustrate optional features or operations unless specified otherwise. All publications, patent applications, patents, and other references mentioned herein are incorporated herein by reference in their entireties.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. As used herein, phrases such as "between X and Y" and "between about X and Y" should be

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interpreted to include X and Y. As used herein, phrases such as "between about X and Y" mean "between about X and about Y." As used herein, phrases such as "from about X to Y" mean "from about X to about Y."

Unless otherwise defined, all terms (including technical and scientific
5 terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the specification and relevant art and should not be interpreted
10 in an idealized or overly formal sense unless expressly so defined herein. Well-known functions or constructions may not be described in detail for brevity and/or clarity.

It will be understood that when an element is referred to as being "on", "attached" to, "connected" to, "coupled" with, "contacting", etc., another
15 element, it can be directly on, attached to, connected to, coupled with or contacting the other element or intervening elements may also be present. In contrast, when an element is referred to as being, for example, "directly on", "directly attached" to, "directly connected" to, "directly coupled" with or "directly contacting" another element, there are no intervening elements present. It will
20 also be appreciated by those of skill in the art that references to a structure or feature that is disposed "adjacent" another feature may have portions that overlap or underlie the adjacent feature.

Spatially relative terms, such as "under", "below", "lower", "over", "upper" and the like, may be used herein for ease of description to describe one element or
25 feature's relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is inverted, elements described as "under" or "beneath" other elements or features
30 would then be oriented "over" the other elements or features. Thus, the exemplary term "under" can encompass both an orientation of "over" and

"under". The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly. Similarly, the terms "upwardly", "downwardly", "vertical", "horizontal" and the like are used herein for the purpose of explanation only unless
5 specifically indicated otherwise.

It will be understood that, although the terms "first", "second", etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one
10 element, component, region, layer or section from another element, component, region, layer or section. Thus, a "first" element, component, region, layer or section discussed below could also be termed a "second" element, component, region, layer or section without departing from the teachings of the present invention. The sequence of operations (or steps) is not limited to the order
15 presented in the claims or figures unless specifically indicated otherwise.

Methods and apparatus according to embodiments of the present invention may be utilized for accurately identifying live and non-live eggs at any time during embryonic development (also referred to as the incubation period). Embodiments of the present invention are not limited to identification only at
20 particular day (e.g., day eleven) or time period during the embryonic development period. In addition, methods and apparatus according to embodiments of the present invention may be used with any types of avian eggs including, but not limited to, chicken, turkey, duck, geese, quail, pheasant eggs, exotic bird eggs, etc.

25 As would be understood by one skilled in the art, eggs are incubated and processed within a carrier, such as an egg flat. Flats may contain any number of rows, such as seven rows of eggs, with rows of six and seven being most common. Moreover, eggs in adjacent rows may be parallel to one another, as in a "rectangular" flat, or may be in a staggered relationship, as in an "offset" flat.
30 Examples of suitable commercial flats include, but are not limited to, the "CHICKMASTER 54" flat, the "JAMESWAY 42" flat and the "JAMESWAY 84" flat

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(in each case, the number indicates the number of eggs carried by the flat). Egg flats are well known to those of skill in the art and need not be described further herein. The terms "flat" and "carrier" are intended to be used interchangeably herein.

5 Referring now to **Fig. 1**, a detector tool **10** for use in candling eggs, according to some embodiments of the present invention, is illustrated.

The illustrated detector tool **10** is configured for use in an automated candling apparatus such as, but not limited to, the Egg Remover® system from Embrex, Inc., Durham, North Carolina. In operation, a plurality of the detector
10 tools **10**, arranged in an array, are utilized to candle a respective array of eggs supported by an egg carrier, as would be understood by those skilled in the art of the present invention.

The illustrated detector tool **10** includes a substantially waterproof housing **12** with a proximal free end **14** and an elongated distal end **16**. As will be
15 described below, the free end **14** is configured to be positioned in contacting relationship with an egg. The distal end **16** is attached to a frame that raises and lowers the detector tool **10** relative to a carrier containing eggs. Extending from the distal end **16** of the housing **12** is an electrical cable **18** containing wiring that connects the various electrical components contained within the detector tool **10**
20 with a controller and/or other electrical components of a candling apparatus, as would be understood by those skilled in the art of the present invention. Embodiments of the present invention are not limited to the illustrated configuration of the detector tool housing **12**. The detector tool housing **12** may have various shapes, sizes and configurations without limitation. The waterproof
25 housing **12** protects sensitive electronic components disposed therein from liquids, moisture, and debris that may be encountered during candling.

An array of the detector tools **10** are supported in a generally vertical orientation via a frame or other supporting member of a candling apparatus. Conventionally, the frame is movable between a raised position and a lowered
30 position. However, individual detector tools **10** may be configured to be lowered and raised relative to an egg independent of other detector tools in an array.

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When in the lowered position, each detector tool **10** rests on top of a respective egg **5**, as would be understood by those skilled in the art of the present invention.

Disposed within the housing **12** are a pair of light sources **20**. Each light source **20** is configured to emit visible light from the housing free end and illuminate an egg positioned adjacent to the housing free end, as will be described below. Also disposed within the housing is a photodetector **22** that is configured to receive light passing through an egg from the light sources **20** during candling. The photodetector **22** generates an output signal corresponding to the intensity of the light leaving an egg. The photodetector **22** may be any type of detector capable of detecting the wavelength(s) of light emitted by the light sources **20**.

In the illustrated embodiment, the photodetector **22** is positioned between the pair of light sources **20**. However, embodiments of the present invention are not limited to the illustrated configuration of the light sources **20** and photodetector **22**. Various orientations of the light sources **20** and photodetector **22** may be utilized as long as the photodetector is shielded from indirect light from external sources and from direct light from the light sources **20**, as described below. Moreover, although a pair of light detectors **20** are utilized in the illustrated embodiment, a single light source may be utilized in some embodiments and more than two light sources may be utilized in other embodiments. In addition, more than one photodetector **22** may be utilized in accordance with other embodiments of the present invention.

The pair of light sources **20** are configured to illuminate an egg with visible light. For example, in some embodiments of the present invention, the pair of light sources **20** are light emitting diodes (LEDs) that are configured to emit light from the visible portion of the spectrum. However, embodiments of the present invention are not limited to the use of LEDs. Various types of light sources may be utilized without limitation. Moreover, optical fibers and light pipes may be utilized to provide light from a remotely-located visible light source.

Each light source **20** is configured to emit visible light. For example, in some embodiments, each light source **20** emits light within a range of between

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about 600 nanometers (nM) and 740 nM. In other embodiments, each light source **20** is configured to emit light within a range of between about 610 nM and 720 nM. Applicants have found that LEDs with center wavelengths (peak intensity) of 625 nM, 639 nM, 660 nM, and 695 nM are particularly effective in
5 detecting the existence of an avian embryo pulse.

Exemplary light sources **20** that may be utilized are the following LED models which are available from Digi-Key Corporation, Thief River Falls, Minnesota: 516-1367-ND, 160-1625-ND and 404-1104-ND, with respective central wavelengths of 625 nM, 639 nM and 660 nM. Another light source **20**
10 that may be utilized is the following LED model which is available from Roithner LaserTechnik, Vienna, Austria: ELD 700-524-3 with a central wavelength of 695 nM.

As illustrated in **Figs. 2a-2b**, the housing free end **14** includes a transparent window **24** that permits light to pass therethrough. The transparent
15 window may be formed from various types of material, without limitation. Exemplary materials include, but are not limited to, glass, sapphire, and plastic (e.g., non-reflecting, transparent plastic, etc.). As illustrated in **Fig. 2b**, the pair of light sources **20** are disposed within the housing and emit light through the window **24**, and the photodetector **22** is disposed within the housing and receives
20 light leaving an egg through the window **24**. The window **24** may be secured to the housing free end **14** in various ways to ensure that the housing remains substantially waterproof.

A replaceable bumper **26** is secured to the housing free end **14** and is configured to engage an egg in contacting relation therewith when the detector
25 tool **10** is lowered onto the egg **5** (**Fig. 3**). In some embodiments, the bumper is formed from a compliant material, such as rubber or other resilient material, in order to cushion contact with an egg. An exemplary material includes, but is not limited to, silicone, rubber, etc. with a dark (e.g., black, etc.) colorant. In other embodiments of the present invention, the bumper may be formed from a rigid
30 material. The bumper **26** may have any of various shapes and sizes and is not limited to the illustrated configuration.

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The bumper **26** is the only portion of the illustrated detector tool **10** that makes contact with an egg. In some embodiments, the bumper **26** is removably secured to the housing free end **14** to facilitate cleaning and/or replacement thereof. The bumper **26** may be removably secured to the housing free end **14** in various ways, without limitation. For example, the housing free end **14** may have dovetail-shaped slots formed therein that are configured to receive correspondingly dovetail-shaped edge portions of the bumper **26**. In other embodiments, the bumper **26** may be removably secured to the housing free end **14** via clips, magnets, adhesives, and/or via various other known methods.

The bumper **26** shields the photodetector **22** from stray light (e.g., light from an external source, etc.) and from direct light from the light sources **20**. In other words, the bumper **26** shields the photodetector **22** from a straight light path from the light source. However, indirect light paths through the egg are allowed, as shown in **Fig. 3**. As illustrated in **Figs. 2a** and **3**, the bumper **26** includes a pair of apertures **28** through which the pair of light sources **20** emit light. The illustrated apertures **28** each have a configuration that causes them to act as respective shields for the light sources **20** such that light emitted by each light source **20** is directed into an egg contacting the bumper **26**. The illustrated bumper **26** also includes an aperture **30** that surrounds the photodetector **22** and shields the photodetector **22** from stray light and from direct light from the light sources **20**. The portion of the egg shell within the aperture **30** is in the shadow of light emitted by an external source. Embodiments of the present invention are not limited to the illustrated shape and configuration of the bumper or of the apertures **28**, **30**. A replaceable bumper **26** may have various shapes and configurations that serve the function of shielding a photodetector **22**, according to embodiments of the present invention.

Photodetector shielding aperture **30** is configured to overlie a portion of an egg **5** in contacting relationship therewith when the detector tool **10** is lowered such that the bumper contacts an egg **5**. The illustrated aperture **30** has a generally hemispherical shape that facilitates stable engagement of the detector tool **10** with an egg. However, embodiments of the present invention are not

limited to the illustrated shape and configuration of aperture 30. In some embodiments, the weight of the detector tool 10 is sufficient to seat the bumper 26 on an egg 5 such that stray light cannot enter the aperture 30 and reach the photodetector 22.

5 In operation and once the detector tool 10 is positioned adjacent to an egg 5, the light sources 20 emit visible light (indicated as 40 in Fig. 3) into the egg 5. The photodetector 22 receives light that leaves the egg 5 and generates an output signal corresponding to the intensity of the light leaving the egg. According to some embodiments of the present invention, the photodetector 22
10 may be provided with an integral amplifier to limit environmental electrical noise (e.g., 60Hz from power lines). According to some embodiments of the present invention, a filter may be utilized to block wavelengths other than wavelengths emitted by the light sources 20. For example, if the light sources 20 emit red light (e.g., 660 nm), then a reduction in sensitivity to non-red light, such as blue and
15 green external light (e.g., from mercury vapor lighting, fluorescent lighting, etc.), can be achieved with a photodetector 22 having a filter that blocks blue (450 nm - 490 nm) and green (490 nm - 560 nm) light. An exemplary filter for blocking blue and green light is a J43-942 red filter, available from Edmund Optics, Inc., Barrington, New Jersey. Amplifiers and filters are well known to those skilled in
20 the art and need not be described further herein.

 A processor 50 disposed within the housing is in communication with the photodetector 22 and processes output signals from the photodetector to determine the viability of an egg 5. Eggs having an embryo pulse and/or movement may be designated as live eggs. Viability may be determined by
25 processing the output signal to determine the existence of cyclical variations in light intensity that correspond to an embryo pulse. Viability may be determined by processing the output signal to determine the existence of non-cyclical variations in light intensity that correspond to embryo movement. In addition, viability may be determined by processing the output signal to determine the
30 existence of both cyclical and non-cyclical variations in light intensity.

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In addition to sensing variations in light level, the photodetector **22** may provide an average light level in an egg that can be used to provide other important information about egg conditions. For example, the average light reflected to the photodetector **22** from a clear egg will be greater than the average light reflected from a live Day 18 egg because the broad beam of light from the light source that impinges upon the side of the egg will reflect throughout the egg rather than being absorbed by a large embryo. Similarly, the average light reaching the photodetector **22** from an upside down egg will be less than that from a normally positioned egg (blunt end up) because more of the embryo is available to block the light. These effects may be enhanced by using a light source having a different wavelength than a light source that is optimal for detecting heartbeat. If multiple light sources with multiple wavelengths are used, then their outputs may be time multiplexed to allow sensing of each wavelength or light source separately with the single photodetector **22**.

Referring now to **Fig. 4**, a detector tool **110** for use in candling eggs, according to other embodiments of the present invention, is illustrated.

The illustrated detector tool **110** includes a substantially waterproof housing **112** with a proximal free end **114** and an elongated distal end **116**. The free end **114** is configured to be positioned in contacting relationship with an egg. The distal end **116** is attached to a frame that raises and lowers the detector tool **110** relative to a carrier containing eggs, as described above. Extending from the distal end **116** of the housing **112** is an electrical cable **118** containing wiring that connects the various electrical components contained within the detector tool **110** with a controller and/or other electrical components of a candling apparatus, as would be understood by those skilled in the art of the present invention.

Disposed within the housing **112** is a photodetector **122** that is configured to receive light passing through an egg from one or more external light sources during candling. As described above, the photodetector **122** generates an output signal corresponding to the intensity of the light leaving an egg. The photodetector **122** may be any type of detector capable of detecting the wavelength(s) of light emitted by a light source.

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As illustrated in **Figs. 5a-5b**, the housing free end **114** includes a transparent window **124** that permits light to pass therethrough. The photodetector **122** is disposed within the housing and receives light leaving an egg through the window **124**. The window **124** may be secured to the housing free end **114** in various ways to ensure that the housing remains substantially waterproof.

A replaceable bumper **126** is secured to the housing free end **114** and is configured to engage an egg in contacting relation therewith when the detector tool **110** is lowered onto the egg **5** (**Fig. 6**). As described above, in some embodiments the bumper is formed from a compliant material, such as rubber or other resilient material, in order to cushion contact with an egg. In other embodiments of the present invention, the bumper **126** may be formed from a rigid material. The bumper **126** may have any of various shapes and sizes and is not limited to the illustrated configuration.

As described above, the bumper **126** is the only portion of the illustrated detector tool **110** that makes contact with an egg. In some embodiments, the bumper **126** is removably secured to the housing free end **114** to facilitate cleaning and/or replacement thereof. The bumper **126** may be removably secured to the housing free end **114** in various ways, without limitation. For example, the housing free end **114** may have dovetail-shaped slots formed therein that are configured to receive correspondingly dovetail-shaped edge portions of the bumper **126**. In other embodiments, the bumper **126** may be removably secured to the housing free end **114** via clips, magnets, adhesives, and/or via various other known methods.

The bumper **126** shields the photodetector **122** from stray light (e.g., light from an external source, etc.) and from direct light from the light sources **120**. The illustrated bumper **126** includes an aperture **130** that surrounds the photodetector **122** and shields the photodetector **122** from stray light and from direct light from the light sources **120**. The portion of the egg shell within the aperture **130** is in the shadow of light emitted by an external source. Embodiments of the present invention are not limited to the illustrated shape and

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configuration of the bumper or of the aperture **130**. A replaceable bumper **126** may have various shapes and configurations that serve the function of shielding a photodetector **122**, according to embodiments of the present invention.

The photodetector shielding aperture **130** is configured to overlie a portion
5 of an egg **5** in contacting relationship therewith when the detector tool **110** is lowered such that the bumper contacts an egg **5**. The illustrated aperture **130** has a generally hemispherical shape that facilitates stable engagement of the detector tool **110** with an egg. However, embodiments of the present invention are not limited to the illustrated shape and configuration of aperture **130**.

10 In operation, and once the detector tool **110** is positioned adjacent to an egg **5**, one or more external light sources **120** emit visible light (indicated as **140** in Fig. 6) into the egg **5**. The photodetector **122** receives light that leaves the egg **5** and generates an output signal corresponding to the intensity of the light leaving the egg. As described above, the photodetector **122** may be provided
15 with an integral amplifier to limit environmental electrical noise, and/or a filter to block wavelengths other than wavelengths emitted by the light sources **120**. A processor **150** disposed within the housing is in communication with the photodetector **122** and processes output signals from the photodetector to determine the viability of an egg **5**.

20 The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention.
25 Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

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THAT WHICH IS CLAIMED IS:

1. An apparatus for candling eggs, comprising:
a housing having a free end;
at least one light source configured to emit visible light from the housing
5 free end and illuminate an egg positioned adjacent to the housing free end,
wherein the at least one light source emits visible light within a range of between
600 nM and 740 nM; and
a photodetector at the housing free end that generates an output signal
corresponding to intensity of light from the at least one light source leaving the
10 egg, wherein the photodetector is shielded from external light and from direct
light from the at least one light source.
2. The apparatus of Claim 1, wherein the at least one light source and
the photodetector are disposed within the housing.
3. The apparatus of Claim 1, wherein the at least one light source
15 comprises a pair of light sources.
4. The apparatus of Claim 3, wherein the photodetector is positioned
between the pair of light sources.
5. The apparatus of Claim 1, wherein the housing free end comprises
a transparent window, wherein the at least one light source is disposed within the
20 housing and emits light through the window, and wherein the photodetector is
disposed within the housing and receives light leaving an egg through the
window.
6. The apparatus of Claim 1, further comprising a bumper secured to
the housing free end that is configured to engage an egg in contacting relation
25 therewith.
7. The apparatus of Claim 6, wherein the bumper comprises a first
aperture through which the at least one light source emits light and a second
aperture through which the photodetector receives light.
8. The apparatus of Claim 6, wherein the bumper shields the
30 photodetector from direct light from the at least one light source.
9. The apparatus of Claim 1, wherein the at least one light

source emits visible light within a range of between 610 nM and 720 nM.

10. The apparatus of Claim 1, wherein the at least one light source comprises a light emitting diode (LED) configured to emit visible light with a peak intensity at one of the following wavelengths: 625 nM, 639 nM,
5 660 nM, and 695 nM.

11. The apparatus of Claim 1, further comprising a processor disposed within the housing that is in communication with the photodetector and that processes the output signal to identify cyclical variations in light intensity, wherein a cyclical variation in light intensity indicates the existence of an embryo
10 pulse.

12. The apparatus of Claim 10, wherein the processor also processes the output signal to identify non-cyclical variations in light intensity, wherein non-cyclical variations in light intensity indicate embryo movement.

13. An apparatus for candling eggs, comprising:
15 a housing having a free end;
a pair of light sources disposed within the housing, wherein each light source is configured to emit visible light from the housing free end and illuminate an egg positioned adjacent to the housing free end, and wherein each light source emits visible light within a range of between 600 nM and 740 nM;
20 a photodetector positioned at the housing free end between the pair of light sources, wherein the photodetector generates an output signal corresponding to intensity of light from the light sources leaving the egg, wherein the photodetector is shielded from external light and from direct light from the light sources; and

25 a processor disposed within the housing that is in communication with the photodetector and that processes the output signal to identify cyclical variations in light intensity, wherein a cyclical variation in light intensity indicates the existence of an embryo pulse.

14. The apparatus of Claim 13, wherein the processor also processes
30 the output signal to identify non-cyclical variations in light intensity, wherein non-cyclical variations in light intensity indicate embryo movement.

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15. The apparatus of Claim 13, further comprising a bumper secured to the housing free end that is configured to engage an egg in contacting relation therewith.

16. The apparatus of Claim 15, wherein the bumper comprises a pair of
5 first and second apertures through which the pair of light sources emit light and a third aperture through which the photodetector receives light.

17. The apparatus of Claim 15, wherein the bumper shields the photodetector from direct light from the pair of light sources.

18. The apparatus of Claim 13, wherein the housing free end
10 comprises a transparent window, wherein the pair of light sources emit light through the window, and wherein the photodetector receives light leaving an egg through the window.

19. The apparatus of Claim 13, wherein the pair of light
15 sources are configured to illuminate an egg with light from one or more selected portions of the spectrum.

20. The apparatus of Claim 13, wherein each light source emits visible light within a range of between 610 nM and 720 nM.

21. The apparatus of Claim 13, wherein each light source comprises a
20 light emitting diode (LED) configured to emit visible light with a peak intensity at one of the following wavelengths: 625 nM, 639 nM, 660 nM, and 695 nM.

22. A method of candling eggs, comprising:
positioning an egg adjacent a free end of a detector tool, wherein the
detector tool has at least one light source and a photodetector;
illuminating the egg with visible light within a range of between 600 nM
25 and 740 nM from the free end via the at least one light source;
detecting intensity of light leaving the egg via the photodetector, wherein
the photodetector is shielded from external light and from direct light from the at
least one light source;
generating an output signal that corresponds to detected light intensity;
30 and

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processing the output signal to identify cyclical and/or non-cyclical variations in light intensity, wherein cyclical variations in light intensity indicate the existence of an embryo pulse, and wherein non-cyclical variations in light intensity indicate embryo movement.

5 23. The method of Claim 22, wherein illuminating the egg with visible light comprises illuminating the egg with visible light within a range of between 610 nM and 720 nM.

 24. The method of Claim 22, wherein the at least one light source comprises a light emitting diode (LED) configured to emit visible
10 light with a peak intensity at one of the following wavelengths: 625 nM, 639 nM, 660 nM, and 695 nM.

 25. The method of Claim 22, wherein a bumper is secured to the detector tool free end, and wherein the positioning step comprises contacting the egg with the bumper.

15 26. A method of candling eggs, comprising:
 contacting an egg with a free end of a detector tool, wherein a bumper is secured to the detector tool free end, and wherein the detector tool has a photodetector;

 illuminating the egg with visible light from at least one light source,
20 wherein the at least one light source emits visible light within a range of between 600 nM and 740 nM;

 detecting intensity of light leaving the egg via the photodetector, wherein the photodetector is shielded from direct light from the light source via the bumper;

25 generating an output signal that corresponds to detected light intensity;
 and

 processing the output signal to identify cyclical and/or non-cyclical variations in light intensity, wherein cyclical variations in light intensity indicate the existence of an embryo pulse, and wherein non-cyclical variations in light
30 intensity indicate embryo movement.