

What is claimed is:

1. A method for enhancing accuracy and efficiency in automated visual inspection of vessels, the method comprising:
 - orienting a vessel containing a sample such that a line scan camera has a profile view of an edge of a stopper of the vessel;
 - spinning the vessel;
 - capturing, by the line scan camera and while spinning the vessel, a plurality of images of the edge of the stopper, wherein each image of the plurality of images corresponds to a different rotational position of the vessel;
 - generating, by one or more processors and based on at least the plurality of images, a two-dimensional image of the edge of the stopper; and
 - processing, by one or more processors executing an inference model that includes a trained neural network, pixels of the two-dimensional image to generate output data indicative of a likelihood that the sample is defective.
2. The method of claim 1, further comprising:
 - causing, by one or more processors and based on the output data, the vessel to be selectively conveyed to a designated reject area.
3. The method of claim 1, wherein the output data is indicative of whether the sample includes one or more objects of a particular type or types.
4. The method of claim 3, wherein the trained neural network is configured to discriminate between gas-filled bubbles and particles in the sample.
5. The method of claim 1, wherein processing the pixels of the two-dimensional image includes applying intensity values associated with different pixels, or other values derived from the intensity values, to different nodes of an input layer of the trained neural network.
6. The method of claim 1, wherein the vessel is a syringe, the stopper is a plunger, and the edge of the stopper is an edge of a plunger dome that contacts the sample.
7. The method of claim 1, wherein orienting the vessel includes conveying the vessel using a motorized rotary table or starwheel.
8. The method of claim 1, wherein orienting the vessel includes inverting the vessel such that the stopper is beneath the sample.
9. The method of claim 1, wherein spinning the vessel includes rotating the vessel at least 360 degrees about a central axis of the vessel.

10. The method of claim 1, wherein the line scan camera is a first line scan camera, the plurality of images is a first plurality of images, the vessel is a first vessel, and the two-dimensional image is a first two-dimensional image, and wherein the method further comprises:

while orienting the first vessel, also orienting a second vessel such that a second line scan camera has a profile view of an edge of a stopper of the second vessel;

while spinning the first vessel, spinning the second vessel;

while capturing the first plurality of images, capturing, by the second line scan camera and while spinning the second vessel, a second plurality of images of the edge of the stopper of the second vessel, wherein each image of the second plurality of images corresponds to a different rotational position of the second vessel; and

generating a second two-dimensional image based on at least the second plurality of images.

11. The method of claim 1, further comprising:

prior to processing the pixels of the two-dimensional image, training the neural network using labeled two-dimensional images of stopper edges of vessels.

12. The method of claim 11, comprising training the neural network using labeled two-dimensional images of vessels contain samples that include different types, numbers, sizes and positions of objects.

13. An automated visual inspection system comprising:

a line scan camera;

conveying means for orienting a vessel containing a sample such that the line scan camera has a profile view of an edge of a stopper of the vessel;

spinning means for spinning the vessel; and

processing means for

causing the line scan camera to capture, while the spinning means spins the vessel, a plurality of images of the edge of the stopper, wherein each image of the plurality of images corresponds to a different rotational position of the vessel,

generating, based on at least the plurality of images, a two-dimensional image of the edge of the stopper of the vessel, and

processing, by executing an inference model that includes a trained neural network, pixels of the two-dimensional image to generate output data indicative of whether the sample is acceptable.

14. The automated visual inspection system of claim 13, wherein the conveying means is a first conveying means, and wherein the automated visual inspection system further comprises:

second conveying means for conveying the vessel to a designated reject area,

wherein the processing means is further for

causing the second conveying means to selectively convey the vessel to the designated reject area based on the output data.

15. The automated visual inspection system of claim 13, wherein the output data is indicative of whether the sample includes one or more objects of a particular type.

16. The automated visual inspection system of claim 15, wherein the trained neural network is configured to discriminate between gas-filled bubbles and particles in the sample.

17. The automated visual inspection system of claim 13, wherein the processing means processes the pixels of the two-dimensional image at least by applying intensity values associated with different pixels, or other values derived from the intensity values, to different nodes of an input layer of the trained neural network.

18. The automated visual inspection system of claim 13, wherein the vessel is a syringe, the stopper is a plunger, and the edge of the stopper is an edge of a plunger dome that contacts the sample.

19. The automated visual inspection system of claim 13, wherein the conveying means includes a motorized rotary table or starwheel, and wherein the conveying means orients the vessel at least by conveying the vessel using the motorized rotary table or starwheel.

20. The automated visual inspection system of claim 13, wherein the conveying means inverts the vessel such that the stopper is beneath the sample.

21. The automated visual inspection system of claim 13, wherein the processing means causes the line scan camera to capture the plurality of images while the spinning means spins the vessel at least 360 degrees about a central axis of the vessel.

22. The automated visual inspection system of claim 13, wherein:
the line scan camera is a first line scan camera, the plurality of images is a first plurality of images, the vessel is a first vessel, the sample is a first sample, the conveying means is a first conveying means, the spinning means is a first spinning means, the two-dimensional image is a first two-dimensional image, and the output data is first output data;
the automated visual inspection system further comprises a second line scan camera, a second conveying means, and a second spinning means;
the second conveying means is for, while the first conveying means orients the first vessel, orienting a second vessel such that the second line scan camera has a profile view of an edge of a stopper of the second vessel;
the second spinning means is for spinning the second vessel while the first spinning means spins the first vessel; and
the processing means is further for
causing the second line scan camera to capture a second plurality of images of the edge of the stopper of the second vessel while the first line scan camera captures the first plurality of images,
generating, based on at least the second plurality of images, a second two-dimensional image of the edge of the stopper of the second vessel, and
processing, by executing the inference model, pixels of the second two-dimensional image to generate second output data indicative of whether the second sample is acceptable.

23. An automated visual inspection system comprising:
a line scan camera;
sample positioning hardware configured to orient a vessel containing a sample such that the line scan camera has a profile view of an edge of a stopper of the vessel, and to spin the vessel while so oriented; and

a memory storing instructions that, when executed by one or more processors, cause the one or more processors to cause the line scan camera to capture, while the vessel is spinning, a plurality of images of the edge of the stopper, wherein each image of the plurality of images corresponds to a different rotational position of the vessel, generate, based on at least the plurality of images, a two-dimensional image of the edge of the stopper of the vessel, and process, by executing an inference model that includes a trained neural network, pixels of the two-dimensional image to generate output data indicative of whether the sample is acceptable.

24. The automated visual inspection system of claim 23, wherein the output data is indicative of whether the sample includes one or more objects of a particular type.

25. The automated visual inspection system of claim 24, wherein the trained neural network is configured to discriminate between gas-filled bubbles and particles in the sample.

26. The automated visual inspection system of claim 23, wherein the instructions cause the one or more processors to process the pixels of the two-dimensional image at least by applying intensity values associated with different pixels, or other values derived from the intensity values, to different nodes of an input layer of the trained neural network.

27. The automated visual inspection system of claim 23, wherein the vessel is a syringe, the stopper is a plunger, and the edge of the stopper is an edge of a plunger dome that contacts the sample.

28. The automated visual inspection system of claim 23, wherein the sample positioning hardware includes a motorized rotary table or starwheel, and orients the vessel at least by conveying the vessel using the motorized rotary table or starwheel.

29. The automated visual inspection system of claim 23, wherein the sample positioning hardware inverts the vessel such that the stopper is beneath the sample.

30. The automated visual inspection system of claim 23, wherein the instructions cause the one or more processors to:

cause the line scan camera to capture the plurality of images while the vessel spins at least 360 degrees about a central axis of the vessel.