types of particles and specific types of bubbles, etc. The robotic inspection platform may also be configured to facilitate the initial (pre-production) development or training of pattern recognition models. In some examples, the platform may be used to perform the primary (e.g., sole or initial) inspection of containers and/or samples. Alternatively, the platform may be used to re-inspect containers and/or samples that have already been identified as rejects, or potential rejects, by another automated inspection system (e.g., a conventional automated inspection system that is less reliable/accurate).

[0005] In examples where the platform implements a machine learning model, the model may be trained using a large data set of training images and a supervised learning technique. The platform may be used to capture the training images under controlled conditions (e.g., precise, repeatable container orientations and lighting conditions), after which a human analyst may manually label attributes of the training images. For example, the analyst may label/classify objects within the training images as specific object types. To capture the training images, a robotic arm of the platform may sequentially pick up each of a number of containers, present the containers in front of the imager, and manipulate (e.g., rotate) the containers while images are acquired at different angles/orientations. Containers with purposely introduced defects (and/or holding samples with purposely introduced defects) may be used in the training process to ensure that the human analyst will encounter a sufficiently broad range of defects and/or defect types when performing the classification task.

[0006] Once the model is trained and integrated, the platform may switch to a "production," "run-time," "operational" or "processing" mode in which the robotic arm retrieves new containers (possibly holding samples), and manipulates the containers in front of the imager in the same manner that was done during the training process. The images for each container may be saved in memory, and processed by a computer using the trained pattern recognition model. The computer may also process the model outputs by applying one or more criteria to determine whether the container is acceptable, or a "reject." If the container is rejected (due to a sample within the container having defects, and/or the container itself having defects), the robotic arm may place the container in a bin or other area specifically reserved for that purpose. The robotic inspection platform may be configured to inspect only containers, to inspect only product samples (e.g., fluids or lyophilized products within the containers), or to inspect both containers and samples, depending on the example. In one example, a single robotic inspection platform can perform any of these functions, so long as the appropriate machine learning models are deployed.

[0006a] According to a first aspect of the present invention, there is provided a robotic inspection platform, comprising:

a robotic arm comprising an end effector and a plurality of articulable segments;

an imaging system comprising an imager; and

a controller configured to

cause the robotic arm to retrieve, using the end effector, a container,

cause the robotic arm to manipulate the container using the end effector, such that the container is sequentially placed in a plurality of orientations while the container is in view of the imager,

cause the imager to capture a plurality of images, with each of the plurality of images being captured while the container is in a respective one of the plurality of orientations,

determine one or more attributes of the container and a sample within the container, by analyzing the plurality of images using a pattern recognition model, the one or more attributes of the container including a presence of one or more chips or cracks,

determine, based on the one or more attributes of the container and/or the sample, whether the container and the sample satisfies one or more criteria, and

based on whether the container and the sample satisfies the one or more criteria, either (i) cause the robotic arm to place the container in an area reserved for rejected containers and/or samples that have failed to satisfy the one or more criteria, or (ii) cause the robotic arm to place the container in an area reserved for containers and/or samples that have not been rejected.

[0006b] According to a second aspect of the present invention, there is provided a method for performing inspection of containers using pattern recognition, the method comprising:

causing a robotic arm to retrieve, using an end effector of the robotic arm, a container;

causing the robotic arm to manipulate the container using the end effector, such that the container is sequentially placed in a plurality of orientations while the container is in view of an imager;

causing the imager to capture a plurality of images, with each of the plurality of images being captured while the container is in a respective one of the plurality of orientations;

determining one or more attributes of the container and a sample within the container, by analyzing the plurality of images using a pattern recognition model, the one or more attributes of the container including a presence of one or more chips or cracks;

determining, based on the one or more attributes of the container and the sample, whether the container and the sample satisfies one or more criteria; and

based on whether the container and the sample satisfies the one or more criteria, either (i) causing the robotic arm to place the container in an area reserved for rejected containers and/or samples that have failed to satisfy the one or more criteria, or (ii) causing the robotic arm to place the container in an area reserved for containers and/or samples that have not been rejected.

[0006c] According to a third aspect of the present invention, there is provided a method for performing inspection of containers using pattern recognition, the method comprising:

causing a robotic arm to retrieve, using an end effector of the robotic arm, a container;

causing an imager to be sequentially placed in a plurality of orientations while the container is in view of the imager;

causing the imager to capture a plurality of images of the container, with each of the plurality of images being captured while the imager is in a respective one of the plurality of orientations;

determining one or more attributes of the container and a sample by analyzing the plurality of images using a pattern recognition model, the one or more attributes of the container including a presence of one or more chips or cracks;

determining, based on the one or more attributes of the container and the sample, whether the container and the sample satisfies one or more criteria; and

based on whether the container and the sample satisfies the one or more criteria, either (i) causing the robotic arm to place the container in an area reserved for rejected containers and/or samples that have failed to satisfy the one or more criteria, or (ii) causing the robotic arm to place the container in an area reserved for containers and/or samples that have not been rejected.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The skilled artisan will understand that the figures, described herein, are included for purposes of illustration and are not limiting on the present disclosure. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the present disclosure. It is to be understood that, in some instances, various aspects of the described implementations may be shown

What is claimed is:

1. A robotic inspection platform, comprising:

a robotic arm comprising an end effector and a plurality of articulable segments;

an imaging system comprising an imager; and

a controller configured to

cause the robotic arm to retrieve, using the end effector, a container,

cause the robotic arm to manipulate the container using the end effector, such that the container is sequentially placed in a plurality of orientations while the container is in view of the imager,

cause the imager to capture a plurality of images, with each of the plurality of images being captured while the container is in a respective one of the plurality of orientations,

determine one or more attributes of the container and a sample within the container by analyzing the plurality of images using a pattern recognition model, the one or more attributes of the container including a presence of one or more chips or cracks,

determine, based on the one or more attributes of the container and/or the sample, whether the container and the sample satisfies one or more criteria, and

based on whether the container and the sample satisfies the one or more criteria, either (i) cause the robotic arm to place the container in an area reserved for rejected containers and/or samples that have failed to satisfy the one or more criteria, or (ii) cause the robotic arm to place the container in an area reserved for containers and/or samples that have not been rejected.

2. The robotic inspection platform of claim 1, wherein the controller is configured to determine the one or more attributes of the container and the sample by analyzing the plurality of images using a machine learning model, the machine learning model being trained to classify container and sample attributes.

3. The robotic inspection platform of claim 2, wherein the controller is configured to facilitate training of the machine learning model at least by:

causing the robotic arm to sequentially retrieve, using the end effector, a plurality of training containers; and

for each of the plurality of training containers that is retrieved, (i) causing the robotic arm to manipulate the training container using the end effector such that the training container is sequentially placed in the plurality of orientations while the training container is in view of the imager, (ii) causing the imager to capture a respective plurality of training images, with each of the respective plurality of training images being captured while the training container is in a respective one of the plurality of orientations, and (iii) causing the respective plurality of images to be presented to a user via a display to facilitate manual labeling of attributes for the training container and/or a sample within the training container.

4. The robotic inspection platform of any one of claims 1 through 3, wherein the controller is configured to distinguish between different types of objects by analyzing the plurality of images using the pattern recognition model.

5. The robotic inspection platform of claim 4, wherein the different types of objects include bubbles and particles.

6. The robotic inspection platform of claim 4 or 5, wherein the different types of objects include one or both of (i) specific types of bubbles and (ii) specific types of particles.

7. The robotic inspection platform of any one of claims 4 through 6, wherein the one or more criteria include at least one criterion dependent upon object type.

8. The robotic inspection platform of any one of claims 1 through 7, wherein the plurality of orientations includes a plurality of rotations about a longitudinal axis of the container.

9. The robotic inspection platform of any one of claims 1 through 8, wherein the area reserved for rejected containers and/or samples is a bin.

10. The robotic inspection platform of any one of claims 1 through 9, wherein the controller is configured to cause the robotic arm to retrieve the container from a plate.

11. The robotic inspection platform of claim 10, wherein the area reserved for containers and/or samples that have not been rejected is an area within the plate.

12. A method for performing inspection of containers using pattern recognition, the method comprising:

causing a robotic arm to retrieve, using an end effector of the robotic arm, a container;

causing the robotic arm to manipulate the container using the end effector, such that the container is sequentially placed in a plurality of orientations while the container is in view of an imager;

causing the imager to capture a plurality of images, with each of the plurality of images being captured while the container is in a respective one of the plurality of orientations;

determining one or more attributes of the container and a sample within the container, by analyzing the plurality of images using a pattern recognition model, the one or more attributes of the container including a presence of one or more chips or cracks;

determining, based on the one or more attributes of the container and the sample, whether the

container and the sample satisfies one or more criteria; and

based on whether the container and the sample satisfies the one or more criteria, either (i) causing the robotic arm to place the container in an area reserved for rejected containers and/or samples that have failed to satisfy the one or more criteria, or (ii) causing the robotic arm to place the container in an area reserved for containers and/or samples that have not been rejected.

13. The method of claim 12, wherein determining the one or more attributes of the container and the sample by analyzing the plurality of images using a pattern recognition model includes:

determining the one or more attributes of the container and the sample by analyzing the plurality of images using a machine learning model, the machine learning model being trained to classify container and sample attributes.

14. The method of claim 13, further comprising facilitating training of the machine learning model at least by:

causing the robotic arm to sequentially retrieve, using the end effector, a plurality of training containers; and

for each of the plurality of training containers that is retrieved, (i) causing the robotic arm to manipulate the training container using the end effector such that the training container is sequentially placed in the plurality of orientations while the training container is in view of the imager, (ii) causing the imager to capture a respective plurality of training images, with each of the respective plurality of training images being captured while the training container is in a respective one of the plurality of orientations, and (iii) causing the respective plurality of images to be presented to a user via a display to facilitate manual labeling of attributes for the training container and/or a sample within the training container.

15. The method of any one of claims 12 through 14, wherein determining one or more attributes of the container and the sample by analyzing the plurality of images using the pattern recognition model includes distinguishing between different types of objects by analyzing the plurality of images using the pattern recognition model.

16. The method of claim 15, wherein the one or more criteria include at least one criterion dependent upon object type.

17. The method of any one of claims 12 through 16, wherein the plurality of orientations includes a plurality of rotations about a longitudinal axis of the container.

18. A method for performing inspection of containers using pattern recognition, the method comprising:

causing a robotic arm to retrieve, using an end effector of the robotic arm, a container;

causing an imager to be sequentially placed in a plurality of orientations while the container is in view of the imager;

causing the imager to capture a plurality of images of the container, with each of the plurality of images being captured while the imager is in a respective one of the plurality of orientations;

determining one or more attributes of the container and a sample by analyzing the plurality of images using a pattern recognition model, the one or more attributes of the container including a presence of one or more chips or cracks;

determining, based on the one or more attributes of the container and the sample, whether the container and the sample satisfies one or more criteria; and

based on whether the container and the sample satisfies the one or more criteria, either (i) causing the robotic arm to place the container in an area reserved for rejected containers and/or samples that have failed to satisfy the one or more criteria, or (ii) causing the robotic arm to place the container in an area reserved for containers and/or samples that have not been rejected.

19. The method of claim 18, wherein determining the one or more attributes of the container and the sample by analyzing the plurality of images using a pattern recognition model includes:

determining the one or more attributes of the container and the sample by analyzing the plurality of images using a machine learning model, the machine learning model being trained to classify container and/or sample attributes.

20. The method of claim 19, further comprising facilitating training of the machine learning model at least by:

causing the robotic arm to sequentially retrieve, using the end effector, a plurality of training containers; and

for each of the plurality of training containers that is retrieved, (i) causing the imager to be sequentially placed in the plurality of orientations while the training container is in view of the imager, (ii) causing the imager to capture a respective plurality of training images, with each of the respective plurality of training images being captured while the imager is in a respective one of the plurality of orientations, and (iii) causing the respective plurality of images to be presented to a user via a display to facilitate manual labeling of attributes for the training container and/or a sample within the training container.