

TARGETED APPLICATION OF DEEP LEARNING TO AUTOMATED VISUAL INSPECTION EQUIPMENT

FIELD OF DISCLOSURE

[0001] The present application relates generally to automated visual inspection (AVI) systems for pharmaceutical or other products, and more specifically to techniques for detecting and distinguishing particles and other objects (e.g., bubbles) in vessels filled with samples (e.g., solutions).

BACKGROUND

[0002] In certain contexts, such as quality control procedures for manufactured drug products, it is necessary to examine samples (e.g., vessels/containers such as syringes or vials, and/or their contents such as fluid or lyophilized drug products) for defects. The acceptability of a particular sample, under the applicable quality standards, may depend on metrics such as the type and/or size of container defects (e.g., chips or cracks), or the type, number and/or size of undesired particles within a drug product (e.g., fibers), for example. If a sample has unacceptable metrics, it may be rejected and/or discarded.

[0003] To handle the quantities typically associated with commercial production of pharmaceuticals, the defect inspection task has increasingly become automated. However, automated detection of particulates in solution presents a special challenge within the pharmaceutical industry. High detection accuracy is generally difficult to achieve, and becomes even more difficult as higher viscosity solutions inhibit particle motion, which can otherwise be indicative of the particle type. For protein-based products with formulations that release gases that promote the formation of bubbles, conventional particle detection techniques can result in a particularly high rate of false rejects. For example, such techniques may have difficulty distinguishing these bubbles (which may cling to the vessel) from heavy particles that tend to settle/rest against a portion of the vessel (e.g., against a plunger of a syringe filled with a solution).

[0004] Moreover, the specialized equipment used to assist in automated defect inspection has become very large, very complex, and very expensive. A single piece of commercial line equipment may include numerous different AVI stations that each handle different, specific inspection tasks. As just one example, the Bosch® Automatic Inspection Machine (AIM) 5023 commercial line equipment, which is used for the fill-finish inspection stage of drug-filled syringes, includes 14 separate visual inspection stations, with 16 general inspection tasks and numerous cameras and other sensors. As a whole, such equipment may be designed to detect a broad range of defects, including container integrity defects such as large cracks or container closures, cosmetic container defects such as scratches or stains on the container surface, and defects associated with the drug product itself such as liquid color or the presence of foreign particles. Due to the above-noted challenges associated with particle detection and characterization, however, such equipment can require redundancies between AVI stations. In the case of the Bosch® AIM 5023 line equipment, for example, the relatively poor performance of a “stopper edge” inspection station (for detecting and distinguishing heavy particles resting on the dome of a syringe plunger) necessitates that particle inspection also be performed at another, “stopper top” AVI station with additional cameras, in order to achieve acceptable overall levels of particle inspection accuracy. This increases the complexity and cost of the equipment, and/or requires that the “stopper top” AVI station be adapted to perform multiple inspection tasks rather than being optimized for a single task (e.g., detecting defects in the stopper itself).

SUMMARY

[0004a] According to a first aspect of the present invention, there is provided a method for enhancing accuracy and efficiency in automated visual inspection of syringes, the method comprising:

orienting a syringe containing a liquid sample such that a line scan camera has a profile view of an edge of a dome of a stopper of the syringe, with the dome contacting the liquid sample and the line scan camera being angled so as to match a slope of the dome;

spinning the syringe;

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

generating, by one or more processors and based on at least the plurality of images, a two-dimensional image of the edge of the dome; 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 liquid sample is defective, wherein the output data is indicative of whether the liquid sample includes one or more objects of a particular type or types, and wherein the trained neural network is configured to discriminate between gas-filled bubbles and particles in the liquid sample.

[0004b] According to a second aspect of the present invention, there is provided 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 perform the method as defined in the first aspect.

[0005] Embodiments described herein relate to systems and methods in which deep learning is applied to a particular type of AVI station (e.g., within commercial line equipment that may include multiple AVI stations) to synergistically provide substantial improvements to accuracy (e.g., far fewer false rejects and/or false positives). Additionally or alternatively, the described systems and methods may allow advantageous modifications to other AVI stations (e.g., within the same commercial line equipment), such as by allowing other AVI stations to focus exclusively on other tasks, and/or by eliminating other AVI stations entirely.

What is claimed is:

1. A method for enhancing accuracy and efficiency in automated visual inspection of syringes, the method comprising:
 - orienting a syringe containing a liquid sample such that a line scan camera has a profile view of an edge of a dome of a stopper of the syringe, with the dome contacting the liquid sample and the line scan camera being angled so as to match a slope of the dome;
 - spinning the syringe;
 - capturing, by the line scan camera and while spinning the syringe, a plurality of images of the edge of the dome, wherein each image of the plurality of images corresponds to a different rotational position of the syringe;
 - generating, by one or more processors and based on at least the plurality of images, a two-dimensional image of the edge of the dome; 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 liquid sample is defective, wherein the output data is indicative of whether the liquid sample includes one or more objects of a particular type or types, and wherein the trained neural network is configured to discriminate between gas-filled bubbles and particles in the liquid sample.
2. The method of claim 1, further comprising:
 - causing, by one or more processors and based on the output data, the syringe to be selectively conveyed to a designated reject area.
3. 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.
4. The method of claim 1, wherein orienting the syringe includes conveying the syringe using a motorized rotary table or starwheel.
5. The method of claim 1, wherein orienting the syringe includes inverting the syringe such that the stopper is beneath the liquid sample.
6. The method of claim 1, wherein spinning the syringe includes rotating the syringe at least 360 degrees about a central axis of the syringe.
7. 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 syringe is a first syringe, and the two-dimensional image is a first two-dimensional image, and wherein the method further comprises:
 - while orienting the first syringe, also orienting a second syringe such that a second line scan camera has a profile view of an edge of a dome of a stopper of the second syringe;
 - while spinning the first syringe, spinning the second syringe;
 - while capturing the first plurality of images, capturing, by the second line scan camera and while spinning the second syringe, a second plurality of images of the edge of the dome of the stopper of the second syringe, wherein each image of the second plurality of images corresponds to a different rotational position of the second syringe; and

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

8. 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 edges of domes of stoppers of syringes.

9. The method of claim 8, comprising training the neural network using labeled two-dimensional images of syringes contain liquid samples that include different types, numbers, sizes and positions of objects.

10. 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 perform the method of any one of claims 1-9.