

What is claimed is:

1. A machine comprising:
a camera to capture images comprising pixels, each of which has a pixel size corresponding to a distance on a stage in a direction of movement of a sample container;
the stage to move the sample container relative to a field of view of the camera which overlaps the stage, wherein the sample container comprises an array of features having a pitch length in a direction of movement of the sample container;
an illumination source to illuminate the field of view of the camera; and
a controller to obtain an analysis image by performing acts comprising, while a feature from the array of features is in, and is in motion relative to, the field of view of the camera, obtaining one or more exposures of the feature by, for each of the one or more exposures, performing acts comprising:
exposing a sensor of the camera to illumination for a first duration; and
during a period having a second duration and which takes place while the sensor of the camera is exposed to illumination, illuminating the field of view of the camera with the illumination source;
wherein the feature's displacement in the field of view of the camera from beginning to end of the period having the second duration is less than or equal to the pitch length in the direction of movement of the sample container.
2. The machine of claim 1, wherein the feature's displacement in the direction of movement of the sample container in the field of view of the camera from beginning to end of the period having the second duration is less than or equal to the pixel size.
3. The machine of any of claims 1-2, wherein:
obtaining one or more exposures of the feature comprises obtaining a plurality of exposures of the feature;
the acts the controller is to perform comprise overlaying the plurality of exposures of the feature based on translating one or more of the plurality of exposures of the feature.

4. The machine of claim 3, wherein:
the acts the controller is to perform comprise for each exposure, obtaining a corresponding value for the sample container's position when the field of view of the camera was illuminated with the illumination source; and
the controller is to translate one or more of the plurality of exposures of the feature based on differences between the exposures' corresponding values for the sample container's position.
5. The machine of claim 4, wherein:
the machine comprises an encoder to provide values for the sample container's position;
the controller is to, for each exposure, obtain the corresponding value for the sample container's position when the field of view of the camera was illuminated with the illumination source from the encoder.
6. The machine of claim 5, wherein:
the encoder has a resolution to distinguish distances smaller than the distance on the stage corresponding to the pixel size; and
overlaying the plurality of exposures of the feature comprises co-registering each of the plurality of exposures at the resolution of the encoder.
7. The machine of claim 6, wherein co-registering each of the plurality of exposures at the resolution of the encoder comprises, for at least one of the one or more exposures:
obtaining a frequency space representation by taking a fast Fourier transform of the exposure;
translating the frequency space representation by the distance which is not a whole number multiple of the distance on the stage corresponding to the pixel size; and
performing an inverse fast Fourier transform of the translated frequency space representation.

8. The machine of claim 6, wherein co-registering each of the plurality of exposures at the resolution of the encoder comprises, for each of the plurality of exposures:

upsampling that exposure to the resolution of the encoder based on interpolating data between pixels; and

translating one or more of the exposures after upsampling.

9. The machine of claim 3, wherein:

the sample container comprises a plurality of fiducial points; and

the controller is to translate one or more of the plurality of exposures of the feature based on differences in location of the fiducial points between exposures.

10. The machine of any of claims 3-9, wherein:

the analysis image comprises a plurality of pixels, each having a first bit depth; and

each of the plurality of exposures comprises a plurality of pixels, each of which has a second bit depth, wherein the second bit depth is less than the first bit depth.

11. The machine of claim 10, wherein:

each pixel comprised by each image captured by the camera has third bit depth, wherein the third bit depth is greater than the second bit depth;

obtaining the plurality of exposures of the feature comprises, for each exposure:

capturing an image with the camera while the field of view of the camera is illuminated by the illumination source; and

truncating a number of most significant bits of the pixels from the image captured by the camera, wherein the truncated number of most significant bits is equal to the difference between the third bit depth and the second bit depth.

12. The machine of any of claims 1-11, wherein:

a threshold illumination energy dose is required for imaging the feature;

for each of the one or more exposures of the feature, illuminating the field of view of the camera with the illumination source comprises activating the illumination source at a power which:

when multiplied by the second duration, provides an individual exposure energy dose less than the threshold illumination energy dose for imaging the feature; and

when multiplied by the second duration and multiplied by the number of exposures in the plurality of exposures of the feature, provides a collective exposure energy dose greater than the threshold illumination energy dose for imaging the feature.

13. The machine of any of claims 1-12, wherein:

the acts the controller is to perform comprise:

obtaining an image of a reference object with the camera, wherein the reference object comprises a plurality of features having known locations; and

creating a distortion map by performing acts comprising comparing the known locations of the plurality of features comprised by the reference object with apparent locations of the plurality of features in the image of the reference object; and

applying the distortion map to each of the one or more exposures of the feature.

14. The machine of any of claims 1-13, wherein:

the stage is mounted on a frame of the machine using ball bearings;

the camera is to capture images using complementary metal-oxide-semiconductor sensors;

and

the illumination source is a diode laser.

15. The machine of any of claims 1-14, wherein the feature is a nanowell.

16. The machine of any of claims 1-15, wherein:

the analysis image is one of a plurality of analysis images;

the controller is to perform a plurality of sequencing cycles, wherein each analysis image from the plurality of analysis images corresponds to a single sequencing cycle; and

the controller is to determine a cluster polynucleotide for each feature in the sample container based on the plurality of analysis images; and

the controller is to determine a complete polynucleotide for a sample associated with the sample container based on the cluster polynucleotides determined for the features from the sample container.

17. The machine of any of claims 1-16, wherein the array of features comprised by the sample container has a pitch perpendicular to the direction of movement of the sample container which is less than the pitch in the direction of movement of the sample container.

18. The machine of any of claims 1-17, wherein the machine comprises a motor to counteract movement of the stage by translating the field of view of the camera in the direction of movement of the sample container during the period having the second duration.

19. A method comprising:

translating, in a direction of movement, a feature on a stage relative to a field of view of a camera, wherein the camera has a pixel size corresponding to a distance in the direction of movement on the stage, wherein the feature is comprised by an array of features in a sample container, the array of features having a pitch length in the direction of movement;

generating an analysis image by performing acts comprising, while the feature is in, and is in motion relative to, the field of view of the camera, obtaining one or more exposures of the feature by, for each of the one or more exposures, performing acts comprising:

exposing a sensor of the camera to illumination for a first duration;

during a period having a second duration and which takes place while the sensor of the camera is exposed to illumination, illuminating the field of view of the camera with an illumination source;

wherein the feature's displacement of the field of view of the camera from beginning to end of the period having the second duration is less than or equal to the pitch length in the direction of movement.

20. The method of claim 19, wherein the feature's displacement in the direction of movement from beginning to end of the period having the second duration is less than or equal to the pixel size.

21. The method of any of claims 19-20, wherein:
obtaining one or more exposures of the feature comprises obtaining a plurality of exposures of the feature;
the method comprises overlaying the plurality of exposures of the feature to create the analysis image of the feature by performing acts comprising translating one or more of the plurality of exposures of the feature.

22. The method of claim 21, wherein the method comprises:
for each exposure, obtaining a corresponding value for the sample container's position when the field of view of the camera was illuminated with the illumination source;
and
translating one or more of the plurality of exposures of the feature based on differences between the exposures' corresponding values for the sample container's position.

23. The method of claim 22, wherein, for each exposure, the corresponding value for the sample container's position when the field of view of the camera was illuminated with the illumination source is obtained from an encoder.

24. The method of claim 23, wherein:
the encoder has a resolution to distinguish distances smaller than the distance on the stage corresponding to the pixel size;
overlaying the plurality of exposures of the feature comprises co-registering each of the plurality of exposures at the resolution of the encoder.

25. The method of claim 24, wherein co-registering each of the plurality of exposures at the resolution of the encoder comprises, for at least one of the one or more exposures:

obtaining a frequency space representation by taking a fast Fourier transform of the exposure;
translating the frequency space representation by the distance which is not a whole number multiple of the distance on the stage corresponding to the pixel size; and
performing an inverse fast Fourier transform of the translated frequency space representation.

26. The method of claim 24, wherein co-registering each of the plurality of exposures at the resolution of the encoder comprises, for each of the plurality of exposures:

upsampling that exposure to the resolution of the encoder based on interpolating data between pixels; and
translating one or more of the exposures after upsampling.

27. The method of claim 21, wherein:

the sample container comprises a plurality of fiducial points; and
the method comprises translating one or more of the plurality of exposures of the feature based on differences in location of the fiducial points between exposures.

28. The method of claim any of claims 21-27, wherein:

the analysis image comprises a plurality of pixels, each having a first bit depth; and
each of the plurality of exposures comprises a plurality of pixels, each of which has a second bit depth, wherein the second bit depth is less than the first bit depth.

29. The method of claim 28, wherein:

each pixel comprised by each image captured by the camera has third bit depth, wherein the third bit depth is greater than the second bit depth;
obtaining the plurality of exposures of the feature comprises, for each exposure:
capturing an image with the camera while the field of view of the camera is illuminated by the illumination source; and

truncating a number of most significant bits of the pixels from the image captured by the camera, wherein the truncated number of most significant bits is equal to the difference between the third bit depth and the second bit depth.

30. The method of any of claims 19-28, wherein:
a threshold illumination energy dose is required for imaging the feature;
for each of the one or more exposures of the feature, illuminating the field of view of the camera with the illumination source comprises activating the illumination source at a power which:
when multiplied by the second duration, provides an individual exposure energy dose less than the threshold illumination energy dose for imaging the feature; and
when multiplied by the second duration and multiplied by the number of exposures in the plurality of exposures, provides a collective exposure energy dose greater than the threshold illumination energy dose for imaging the feature.
31. The method of any of claims 19-30, wherein the method comprises:
obtaining an image of a reference object with the camera, wherein the reference object comprises a plurality of features having known locations; and
creating a distortion map by performing acts comprising comparing the known locations of the plurality of features comprised by the reference object with apparent locations of the plurality of features in the image of the reference object; and
applying the distortion map to each of the one or more exposures of the feature.
32. The method of any of claims 19-31, wherein:
the stage is mounted on a stationary frame using ball bearings;
the camera is to capture images using complimentary metal-oxide-semiconductor sensors;
and
the illumination source is a diode laser.

33. The method of any of claims 19-32, wherein the feature is a nanowell.

34. The method of any of claims 19-33, wherein:
the analysis image is one of a plurality of analysis images;
the method comprises:

performing a plurality of sequencing cycles, wherein each analysis image from the plurality of analysis images corresponds to a single sequencing cycle;
determining a cluster polynucleotide for each feature in the sample container based on the plurality of analysis images; and
determining a complete polynucleotide for a sample associated with the sample container based on the cluster polynucleotides determined for the features from the sample container.

35. The method of any of claims 19-34, wherein the array of features comprised by the sample container has a pitch perpendicular to the direction of movement of the sample container which is less than the pitch in the direction of movement of the sample container.

36. The method of any of claims 19-35, wherein the method comprises a motor counteracting movement of the stage by translating the field of view of the camera in the direction of movement during the period having the second duration.

37. A machine comprising:
a stage to move a sample relative to a field of view of a camera which overlaps the stage;
the camera to capture images comprising pixels, each of which has a pixel size corresponding to a distance on the stage;
an illumination source to illuminate the field of view of the camera; and
means for obtaining an analysis image of a continuously moving sample using pulsed illumination.

38. The machine of claim 37, wherein the means for obtaining the analysis image of the continuously moving sample using pulsed illumination comprises means for translating and overlaying multiple sub-threshold exposures.