CLAIMS

What is claimed is:

1. A method executed by one or more electronic devices in a robotic system that improves alignment of a robotic arm to an object, the method comprising:

detecting, with Lidar sensors, a salient regular surface on the object;

detecting, with the Lidar sensors, a three-dimensional (3D) protrusion attached to the salient regular surface on the object;

inferring, based on a known location of the 3D protrusion on the object, a component of the object adjacent to the 3D protrusion;

aligning, based on the known location of the 3D protrusion and a known location of the component, the robotic arm with respect to the object;

calibrating a 2D Lidar and the 3D Lidar to determine a correspondence between components monitored by the 2D Lidar and components monitored by the 3D Lidar;

monitoring the components of the object with 2D Lidar and 3D Lidar; and

monitoring movement of surrounding objects with 2D Lidar and 3D Lidar.

2. The method of claim 1, wherein the 3D protrusion is detected on the object without prior knowledge of a shape of the 3D protrusion.

3. The method of claim 1 further comprising:

monitoring movement of the object by building a statistical model for each scanned point of a point cloud determined from data sensed of the Lidar sensors;

determining whether deviations from the statistical model are larger than a threshold;

grouping detected points with large deviations into pieces according to Euclidean distance; and

determining if each of the pieces is a component of the object or an external object.

4. The method of claim 1 further comprising:

detecting the 3D protrusion attached to the salient regular surface by:

segmenting the object from a background of the object;

detecting the salient regular surface by RANSAC;

selecting points connected to the salient regular surface; and

segmenting the points connected to the salient regular surface.

5. The method of claim 1, wherein the object is an automobile, the 3D protrusion is a side mirror on a door of the automobile, the component being inferred is a side window on the door of the automobile, and the salient regular surface is a surface adjacent the window from to which the side mirror attaches.

6. The method of claim 1 further comprising:

detecting, with a 3D Lidar sensor, a car door window when the object is an automobile; and

monitoring, with a 2D Lidar sensor, movement of a door of the automobile.

7. The method of claim 1 further comprising:

generating a 2D point cloud of the object; and

monitoring movements of the object or other objects in the environment within a field of view of the Lidar sensors by observing deviations within the 2D point cloud.

8. A non-transitory computer-readable storage medium that one or more electronic devices in a robotic system executes to improve alignment of a robotic arm to an object, the method comprising:

sensing, with a three-dimensional (3D) sensor and a two-dimensional (2D) sensor, a 3D protrusion on the object and a salient regular surface to which the 3D protrusion attaches;

inferring, based on a known geometry of the object, a component of the object that is next to the 3D protrusion and that is not detectable with the 3D sensor;

moving, based on a location of the 3D protrusion and a location of the component, the robotic arm to deliver an object to the location of the component; and

calibrating the 3D sensor with the 2D sensor using a predetermined object by:

obtaining first set of image data of the object with the 3D sensor;

obtaining second set of image data of the object with the 2D sensor;

generating a first set of coordinates of a point on the predetermined object with the first image data;

generating a second set of coordinates of the point on the predetermined object with the second image data; and

matching the first set of coordinates with the second set of coordinates.

9. The non-transitory computer-readable storage medium of claim 8 in which the method further comprises:

determining a location of a side mirror on the object when the object is an automobile;

inferring, based on the location of the side mirror, a side door window that is adjacent to the side mirror without detecting the side door window; and

moving the robotic arm to the side door window to deliver an object to a person in the automobile.

10. The non-transitory computer-readable storage medium of claim 8 in which the method further comprises:

detecting changes to the object or other objects in the environment by:

receiving point cloud from the 3D and 2D sensors;

estimating a mean distance μ and a standard deviation σ for each point in the point cloud; and

assigning a point as a foreground point when $\frac{|distance-\mu|}{\sigma} > S$, where S is a positive threshold value;

grouping all foreground points into pieces according to Euclidean distance; and

determining whether the foreground pieces belong to the objects or other objects in the environment.

11. The non-transitory computer-readable storage medium of claim 8 in which the method further comprises:

monitoring components of the object with the 3D sensor and the 2D sensor; and

calibrating the 2D sensor and the 3D sensor based on a design pattern of a 3D cube with a triangular hole on each surface, wherein the 3D cube for the 3D sensor is detected from 3D point cloud by template matching, and the 3D cube for the 2D sensor is detected by measuring a length of a projected point cloud on each surface of the 3D cube and a length of broken parts of a projected line.

12. The non-transitory computer-readable storage medium of claim 8, wherein the 3D sensor and the 2D sensor are Lidar sensors positioned around the object, and the object is an automobile.

13. The non-transitory computer-readable storage medium of claim 8 in which the method further comprises:

segmenting protrusions detected on the object into protrusion clusters based on Euclidean distance constraints; and

inferring components that are occluded from the 3D sensor and from the 2D sensor based on the protrusion clusters and on known geometric properties of the object.

14. A robotic system comprising:

two-dimensional (2D) Lidar sensors positioned around an object;

three-dimensional (3D) Lidar sensors positioned around the object;

a computer that includes a memory that stores instructions and a processor that executes the instructions to improve aligning of a robotic arm to the object by:

receiving data from the 2D Lidar sensors and the 3D Lidar sensors;

determining, from the data, a salient regular surface on the object;

determining, from the data, a three-dimensional (3D) protrusion attached to the salient regular surface on the object;

inferring, based on a known geometry of the object, a component of the object that is occluded and not detectable with the 3D Lidar sensors;

moving, based on a location of the 3D protrusion and a location of the component, the robotic arm to align the robotic arm with respect to the location of the component; and

monitoring, based on calibrated 2D Lidar data, movement of components of the object or other objects in the environment.

15. The robotic system of claim 14, wherein the object is an automobile, the 3D protrusion is a side view mirror of the automobile, and the component is a side door window of the automobile.

16. The robotic system of claim 14, wherein the processor further executes the instructions by:

calibrating the 2D Lidar sensors and the 3D Lidar sensors by estimating a first set of locations of a cube from a 2D Lidar coordinate system, estimating a second set of locations of the cube from a 3D Lidar coordinate system, and matching the first set of locations with the second set of locations.

17. The robotic system of claim 14, wherein the processor further executes the instructions by:

generating a 2D point cloud of the object; and

monitoring dynamic changes to the object within a field of view of the 2D Lidar sensors and the 3D Lidar sensors by observing deviations within the 2D point cloud.

18. The robotic system of claim 14, wherein the regular salient surfaces are smooth surfaces that include planes, spheres, and cylinders.