Claims

1. A method for calibration of cooperative sensors, the method comprising:

obtaining a first set of sensor data for an environment from a first sensor;

obtaining a second set of sensor data for the environment from a second sensor that is cooperative with the first sensor;

identifying one or more objects from the first set of sensor data and the second set of sensor data, wherein the one or more objects comprise one or more dynamic objects;

generating a first point cloud data (PCD) representation for the one or more objects identified from the first set of sensor data;

generating a second point cloud data (PCD) representation for the one or more objects identified from the second set of sensor data;

identifying one or more common objects that are present in both the first PCD representation and the second PCD representation;

identifying feature point pairs for each object in the one or more common objects, wherein each feature point pair of the feature point pairs comprises one or more feature points extracted from the first PCD representation and/or the second PCD representation corresponding to a same or similar feature of the object; and

for each feature point pair of the feature point pairs, minimizing a distance between feature points in the feature point pair so as to form an extrinsic calibration matrix for calibrating the second sensor based on the first sensor.

2. The method according to claim 1, wherein the obtaining of the first set of sensor data comprises obtaining one or more frames of the first sensor, and wherein the obtaining of the second set of sensor data comprises obtaining one or more frames of the second sensor.

3. The method according to claim 1, wherein the first sensor has a first field of view, the second sensor has a second field of view, and the first field of view overlaps with the second field of view.

4. The method according to claim 1, wherein the one or more objects further comprise one or more static objects.

5. The method according to any one of the preceding claims, further comprising:

identifying the one or more common objects that are present in both the first PCD representation and the second PCD representation using prior knowledge or applying coarse sensor fusion to identify a common field of view for the first sensor and the second sensor, and

projecting the one or more common objects into a frame of reference of the second sensor for calibrating the second sensor based on the first sensor.

6. The method according to any one of the preceding claims, further comprising:

obtaining a pose data from one of the first sensor and the second sensor, the pose data indicating a pose of the one of the first sensor and the second sensor;

transforming the first PCD representation and the second PCD representation into a common frame of reference based on the pose, wherein the transforming includes applying a pose correction to one of the first sensor and the second sensor that does not provide the pose data; and

identifying the one or more common objects in the common frame of reference.

7. The method according to any one of the preceding claims, wherein prior to the identifying of one or more common objects that are present in both the first PCD representation and the second PCD representation, the method further comprises:

obtaining a first pose data from the first sensor, the first pose data indicating a first pose of the first sensor;

obtaining a second pose data from the second sensor, the second pose data indicating a second pose of the second sensor;

transforming the first PCD representation and the second PCD representation into a common frame of reference based on the first pose and the second pose; and

identifying the one or more common objects in the common frame of reference.

8. The method according to any one of the preceding claims, wherein prior to the generating of the first PCD representation for the one or more objects identified from the first set of sensor data, the method comprises:

segmenting the one or more objects from the first set of sensor data and the second set of sensor data based on one or more of the following:

a machine/deep learning approach,

a Computer Vision approach, and

prior object knowledge or position and geometry of the one or more objects.

9. The method according to any one of claims 1 to 7, further comprising:

segmenting while identifying the one or more objects from the first set of sensor data and the second set of sensor data based on one or more of the following:

a machine/deep learning approach,

a Computer Vision approach, and

prior object knowledge or position and geometry of the one or more objects.

10. The method according to claim 1, wherein the first sensor or the second sensor is one of the following:

a camera sensor,

a Light Detection and Ranging (LiDAR) sensor,

a Radio Detection and Ranging (RADAR) sensor,

an ultrasonic sensor,

a proximity or distance sensor, and

a range sensor.

11. The method according to any one of the preceding claims, wherein the feature points are extracted from the first PCD representation and/or the second PCD representation using a deep learning approach, wherein the extracted feature points comprise uniformly sampled representation and/or Centroid representation, and wherein the deep learning approach comprises one of PointNet and STN-based approaches.

12. The method according to any one of the preceding claims, wherein the identifying of feature point pairs for each object in the one or more common objects is based on one or more of the following:

an Iterative Closest Point (ICP) algorithm,

a k-nearest neighbors (KNN) algorithm, and

a density-based clustering algorithm.

13. A system for calibration of cooperative sensors, the system comprising:

at least one processor; and

a memory including computer program code for execution by the at least one processor, the computer program code instructs the at least one processor to:

obtain a first set of sensor data for an environment from a first sensor;

obtain a second set of sensor data for the environment from a second sensor that is cooperative with the first sensor;

identify one or more objects from the first set of sensor data and the second set of sensor data, wherein the one or more objects comprise one or more dynamic objects;

generate a first point cloud data (PCD) representation for the one or more objects identified from the first set of sensor data;

generate a second point cloud data (PCD) representation for the one or more objects identified from the second set of sensor data;

identify one or more common objects that are present in both the first PCD representation and the second PCD representation;

identify feature point pairs for each object in the one or more common objects, wherein each feature point pair of the feature point pairs comprises one or more feature points extracted from the first PCD representation and/or the second PCD representation corresponding to a same or similar feature of the object; and

for each feature point pair of the feature point pairs, minimize a distance between feature points in the feature point pair so as to form an extrinsic calibration matrix for calibrating the second sensor based on the first sensor.

14. The system according to claim 13, wherein the first set of sensor data comprises one or more frames of the first sensor, and the second set of sensor data comprises one or more frames of the second sensor.

15. The system according to claim 13, wherein the first sensor has a first field of view, the second sensor has a second field of view, and the first field of view overlaps with the second field of view.

16. The system according to claim 13, wherein the one or more objects further comprise one or more static objects.

17. The system according to any one of claims 13 to 15, wherein the system is further configured to:

identify the one or more common objects that are present in both the first PCD representation and the second PCD representation using prior knowledge or applying coarse sensor fusion to identify a common field of view for the first sensor and the second sensor, and

project the one or more common objects into a frame of reference of the second sensor for calibrating the second sensor based on the first sensor.

18. The system according to any one of claims 13 to 15, wherein the system is further configured to:

obtain a pose data from at least one of the first sensor and the second sensor, the pose data indicating a pose of the at least one of the first sensor and the second sensor;

transform the first PCD representation and the second PCD representation into a common frame of reference based on the pose, wherein the transforming includes applying a pose correction to one of the first sensor and the second sensor that does not provide the pose data; and

identify the one or more common objects in the common frame of reference.

19. The system according to any one of claims 13 to 15, wherein prior to the identifying of one or more common objects that are present in both the first PCD representation and the second PCD representation, the system is further configured to:

obtain a first pose data from the first sensor, the first pose data indicating a first pose of the first sensor;

obtain a second pose data from the second sensor, the second pose data indicating a second pose of the second sensor;

transform the first PCD representation and the second PCD representation into a common frame of reference based on the first pose and the second pose; and

identify the one or more common objects in the common frame of reference.

20. The system according to any one of claims 13 to 19, wherein prior to the generating of the first PCD representation for the one or more objects identified from the first set of sensor data, the system is configured to:

segment the one or more objects from the first set of sensor data and the second set of sensor data based on one or more of the following:

a machine/deep learning approach,

a Computer Vision approach, and

prior object knowledge or position and geometry of the one or more objects.

21. The system according to any one of claims 13 to 19, wherein the system is further configured to:

segment while identify the one or more objects from the first set of sensor data and the second set of sensor data based on one or more of the following:

a machine/deep learning approach,

a Computer Vision approach, and

prior object knowledge or position and geometry of the one or more objects.

22. The system according to claim 13, wherein the first sensor or the second sensor is one of the following:

a camera sensor,

a Light Detection and Ranging (LiDAR) sensor,

a Radio Detection and Ranging (RADAR) sensor,

an ultrasonic sensor,

a proximity or distance sensor, and

a range sensor.

23. The system according to any one of claims 13 to 22, wherein the feature points are extracted from the first PCD representation and/or the second PCD representation using a deep learning approach, wherein the extracted feature points comprise uniformly sampled representation and/or Centroid representation, and

wherein the deep learning approach comprises one of PointNet and STN-based approaches.

24. The system according to any one of claims 13 to 23, wherein during the identifying of feature point pairs for each object in the set of object of interest, the system is configured to identify feature point pairs for each object in the one or more common objects based on one or more of the following:

an Iterative Closest Point (ICP) algorithm,

a k-nearest neighbors (KNN) algorithm, and

a density-based clustering algorithm.

25. The system according to any one of claims 13 to 24, wherein the system is one of the following:

a semi-autonomous vehicle,

a fully autonomous vehicle,

an autonomous robot,

a drone,

a ship,

a plane,

an Internet of Things (IoT) system,

an Industry 4.0 system, and

a medical device.

26. A non-transitory computer readable storage medium having instructions encoded thereon that, when executed by a processor, cause the processor to:

obtain a first set of sensor data for an environment from a first sensor;

obtain a second set of sensor data for the environment from a second sensor that is cooperative with the first sensor;

identify one or more objects from the first set of sensor data and the second set of sensor data, wherein the one or more objects comprise one or more dynamic objects;

generate a first point cloud data (PCD) representation for the one or more objects identified from the first set of sensor data;

generate a second point cloud data (PCD) representation for the one or more objects identified from the second set of sensor data;

identify one or more common objects that are present in both the first PCD representation and the second PCD representation;

identify feature point pairs for each object in the one or more common objects, wherein each feature point pair of the feature point pairs comprises one or more feature points extracted from the first PCD representation and/or the second PCD representation corresponding to a same or similar feature of the object; and

for each feature point pair of the feature point pairs, minimize a distance between feature points in the feature point pair so as to form an extrinsic calibration matrix for calibrating the second sensor based on the first sensor.