Sensor Placement Optimization using Random Sample Consensus for Best Views Estimation

Carlos M. Costa[1,2] Germano Veiga[1], Armando Sousa[1,2],
Ulrike Thomas[3] and Luís Rocha[1]

23th IEEE International Conference on
Autonomous Robot Systems and Competitions
(ICARSC 2023)

[1] Centre for Robotics in Industry and Intelligent Systems of INESC TEC, Portugal
[2] Faculty of Engineering of the University of Porto, Portugal
[3] Robotics and Human Machine Interaction Laboratory at the Technical University of Chemnitz, Germany

Presentation Outline

Introduction

Sensors and environments modeling

Sensors deployment

Best views estimation

Conclusions

Context

- Perception of objects with large occlusions is a challenging task that can be tackled using active perception with a moving sensor or with a constellation of sensors.
- The creation of a sensor constellation that maximizes the observable surface area of set of target objects is difficult to optimize when there are large occlusions of the objects and when creating a heterogeneous constellation with different types of sensors that have distinct technical characteristics.

MAIN CONTRIBUTIONS

- Multisensor fusion approach that relies on color segmentation and voxel grid merging of point clouds that were generated in simulated worlds.
- RANSAC algorithm for estimating the type, number and disposition of 3D sensors that maximize the target objects observable surface area.
- Public release[1] of source code and dataset with 4 simulation worlds developed for bin picking and active perception use cases with parts with large occlusions.

[1] https://github.com/carlosmccosta/sensor_placement_optimization

Depth sensors modeling

- Modeling in the Gazebo simulator of 3D sensors with different technical characteristics:
  - Resolution
  - Field of view
  - Minimum and maximum measurement range
  - Sensor acquisition rate
- Creation of simulation models for 3D sensors widely used from several manufacturers:
  - Ensenso
  - Kinect
  - Realsense
  - Orbbec
  - ZED

Environments modeling

- Modeling of 4 different test environments:
  - 1 for active perception with hand occlusions.
  - 1 for bin picking with minimal occlusions.
  - 1 for bin picking with large occlusions.
  - 1 for multiple object bin picking with large occlusions.
- Target object:
  - Starter motor
- Support and occluding objects:
  - Large stacking box
  - Trolley with shelves
  - Differential gearbox
  - Alternator
- The target object model uses a special surface material that ignores light effects (such as shading) and has a unique color (green) that will be used for sensor data segmentation.

Environment for active perception

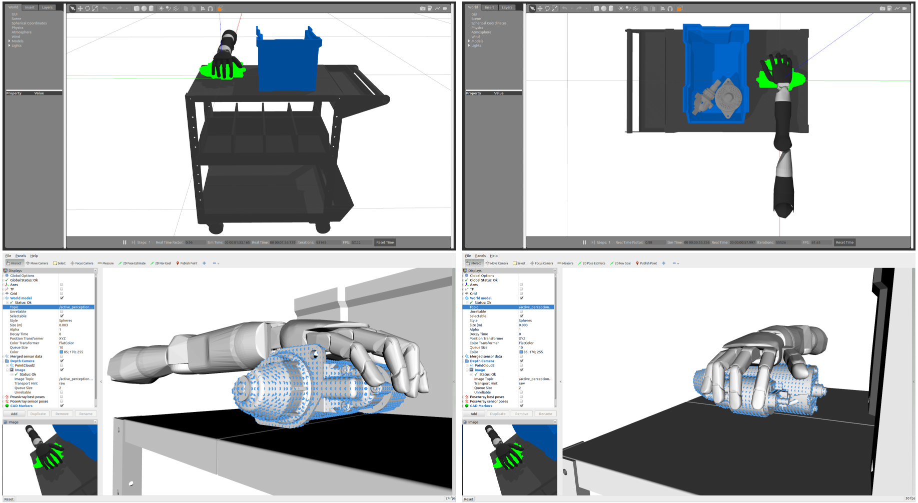

Fig. 1: Environment with a hand occluding a starter motor.

ENVIRONMENT FOR BIN PICKING

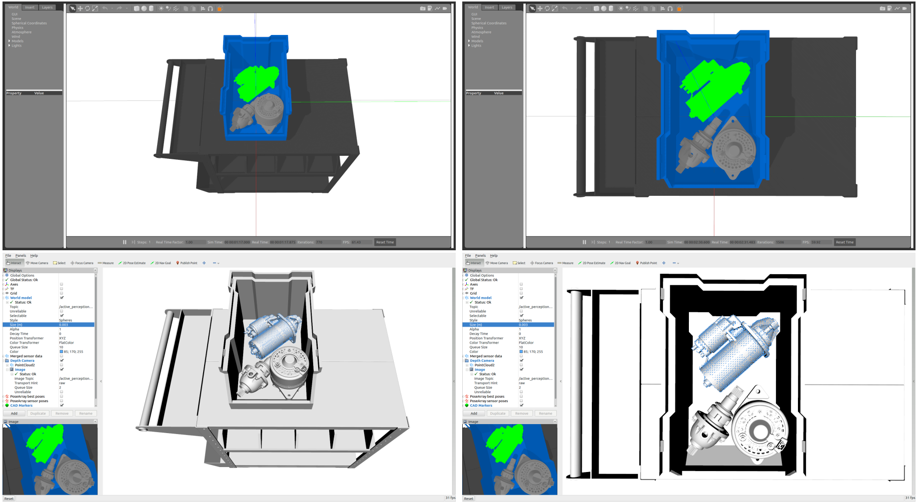

Fig. 2: Environment with a gearbox and an alternator occluding a starter motor.

ENVIRONMENT FOR BIN PICKING WITH OCCLUSIONS

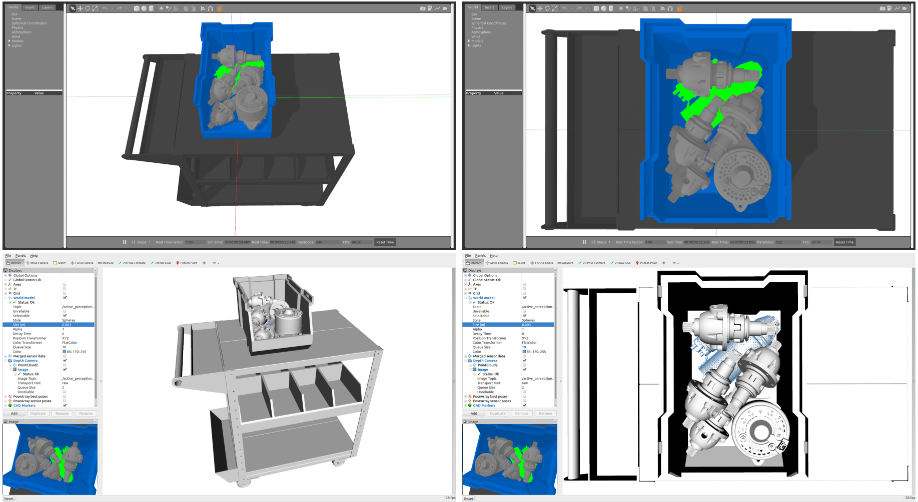

Fig. 3: Environment with gearboxes and an alternator occluding a starter motor.

Environment for multiple bin picking with occlusions

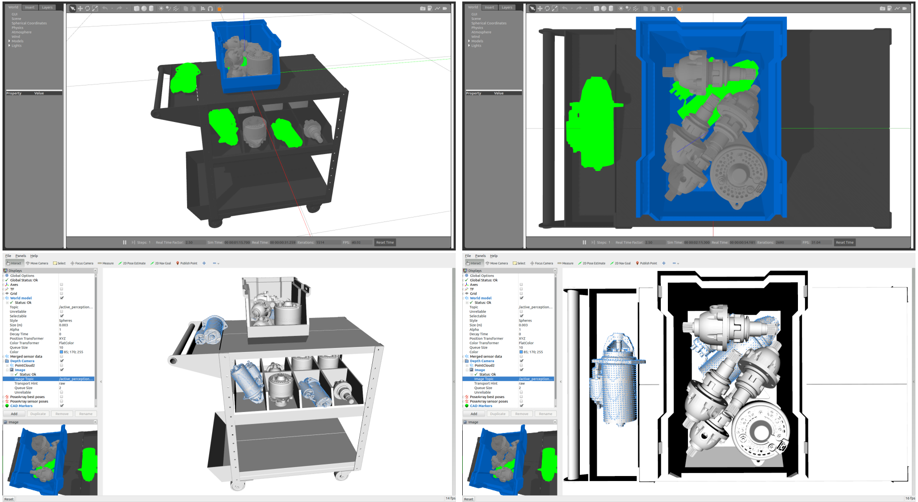

Fig. 4: Environment with gearboxes, an alternator and shelves occluding several starter motors.

Sensors deployment

- Several populations of sensors were added to each simulated world.
- Each population is of a given sensor type and is deployed within a given region of interest.
- Currently supported deployment configurations:
  - Uniform along a line.
  - Uniform within a 2D grid.
  - Uniform or random deployment within a box.
  - Uniform or random deployment within a cylinder.

Sensors deployment for active perception

- For the active perception environment, 450 sensors were deployed close to the target object, on the top, right and back side of the trolley.

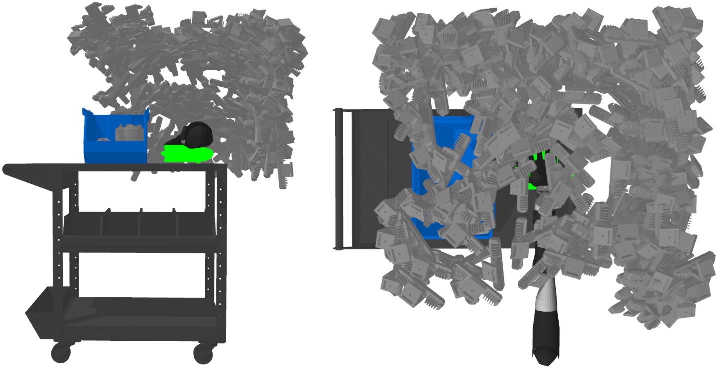

Fig. 5: Sensors deployment for the active perception environment (the CAD models of the sensors are hidden during the generation of the depth image).

Sensors deployment for single object bin picking

- In the world with minimal occlusions it was deployed 100 sensors while in the world with significant occlusions it was deployed 300 sensors.

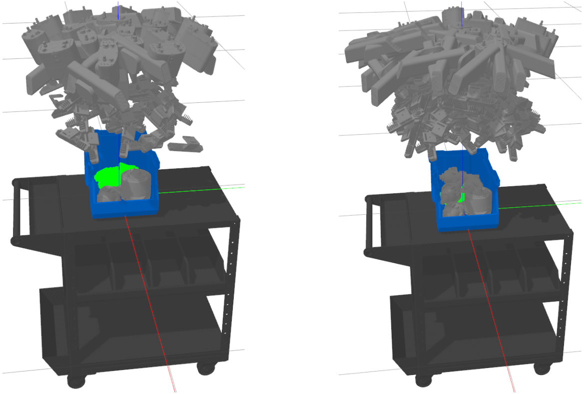

Fig. 6: Sensors deployment for the 2 bin picking environments that had a single target object.

SENSORS DEPLOYMENT FOR MULTIPLE OBJECT BIN PICKING

- For the multiple bin picking environment, given that there were multiple target objects it was deployed 450 sensors across 7 populations:
  - 5 populations simulating fixed sensors on the walls and ceiling.
  - 2 populations above the trolley, simulating dynamic sensors attached to a robotic arm.

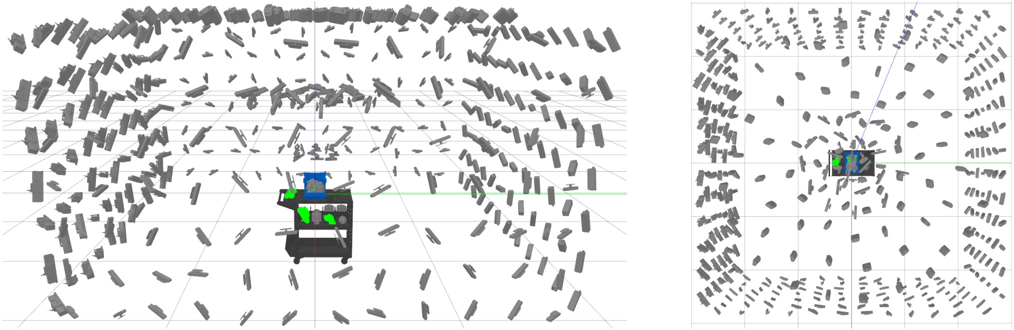

Fig. 7: Sensors deployment for the bin picking environment that had multiple target objects.

REFERENCE POINT CLOUD

- The first step in the processing pipeline includes the generation of the multi-object reference point cloud that is assembled using the CAD data and the objects poses given by the simulator, which is later on filtered with a voxel grid algorithm to perform a regular spatial partition and extract the points that are in the surface voxels centroids.

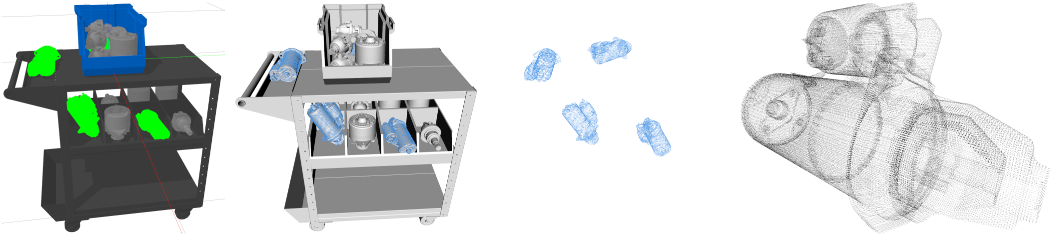

Fig. 8: The first image illustrates the color scene rendering in Gazebo with the target objects in green while the second and third images display the reference point cloud that was generated from the CAD points data shown on the last image.

Data analysis for each sensor

- Color segmentation is performed to identify the sensor image pixels that belong to the target objects (which have a unique green material that does not render shadows).
- For each image pixel associated with a target object, the 3D depth point is computed from the z-buffer depth image using the pinhole camera model.
- The generated point cloud is transformed from the sensor into the world coordinate system.
- A voxel grid filtering algorithm is applied to perform a regular space partition in which the centroid is computed for each voxel.
  - Critical for allowing consistent evaluation of the object(s) observed surface area coverage percentage, even when the sensors have different resolution and are at different distances from the target object(s).

DATA ANALYSIS FOR EACH SENSOR

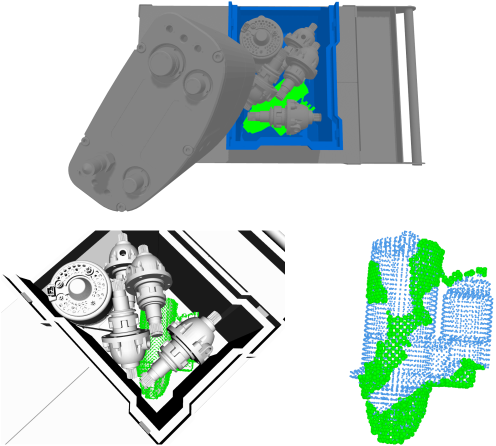

Fig. 9: Color image rendered with the Gazebo simulator along with the generated point cloud for the target object taking into consideration the environment occlusions.

Estimation of the best sensor

If only one sensor is enough (decision made by the system user):

- The surface area percentage for each sensor is analyzed.
- The sensor with the highest surface area percentage coverage of the target object(s) is chosen.

Estimation of the sensor constellation

- Using a Random Sample Consensus (RANSAC) approach, a set of N sensors is selected randomly.
- The sensor data from the selected sensors is merged using a voxel grid algorithm to ensure that there is only one point per voxel.
- The observable surface area percentage for the selected sensors is computed.
- If the current subset of sensors achieved better observable surface area percentage than the current best, then it becomes the current best views estimation for the sensor disposition.
- At the end of a given number of iterations or if the observable surface area percentage reaches a given threshold, the search is terminated, returning the best sensor constellation found.

Active perception environment - 1 sensor

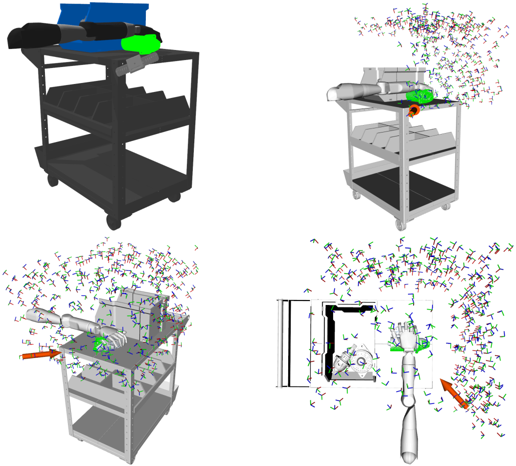

Fig. 10: Estimation of the best sensor for the active perception environment with a 27% of surface area coverage.

Active perception environment - 3 sensors

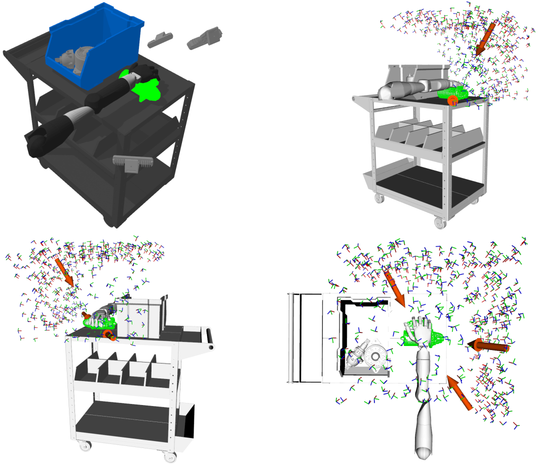

Fig. 11: Estimation of the 3 best sensors for the active perception environment with a 62% of surface area coverage.

BIN PICKING ENVIRONMENT - 1 SENSOR

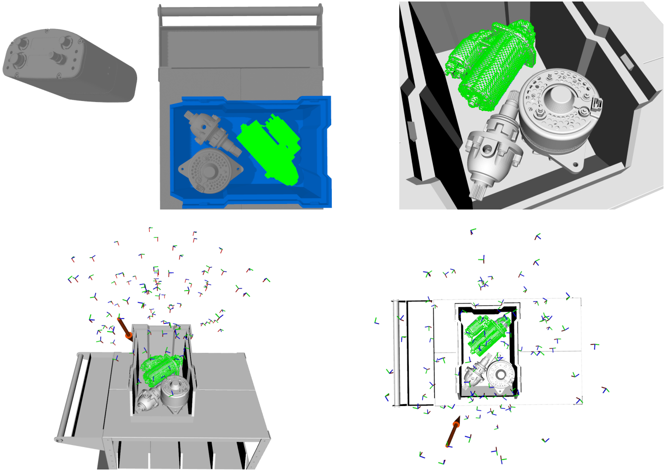

Fig. 12: Estimation of the best sensor for the bin picking environment with a 45% of surface area coverage.

Bin picking environment - 5 sensors

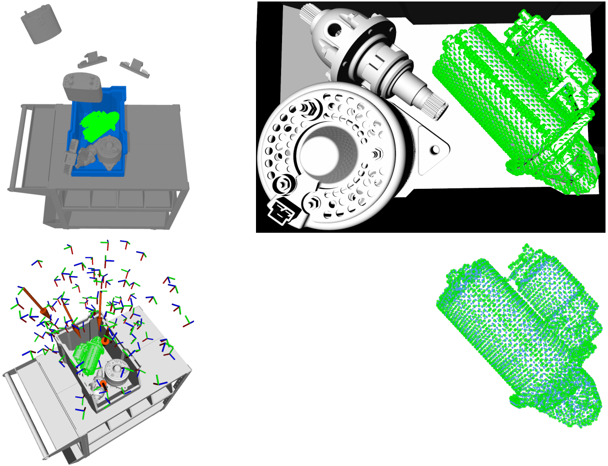

Fig. 13: Estimation of the 5 best sensors for the bin picking environment with a 65% of surface area coverage.

Bin picking with occlusions environment - 1 sensor

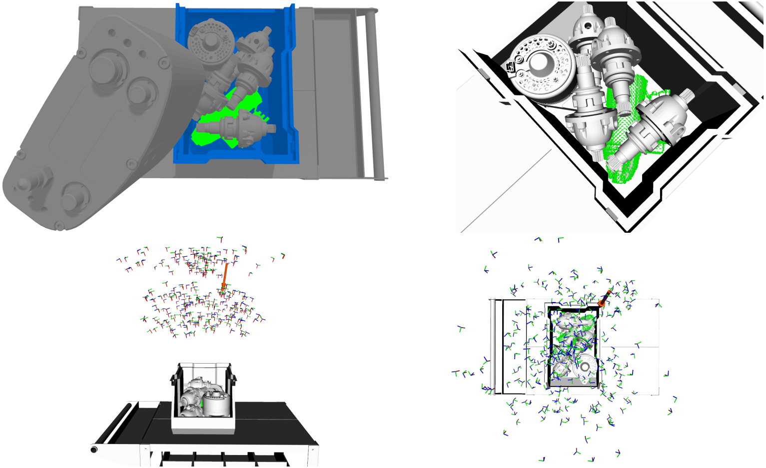

Fig. 14: Estimation of the best sensor for the bin picking with occlusions environment with a 19% of surface area coverage.

Bin picking with occlusions environment - 3 sensors

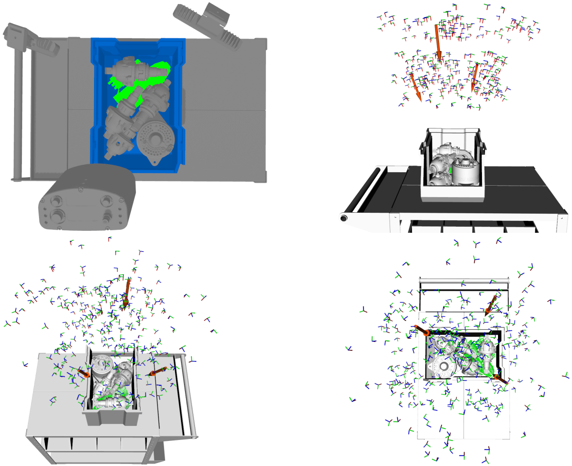

Fig. 15: Estimation of the 3 best sensors for the bin picking with occlusions environment with a 31% of surface area coverage.

Multiple bin picking with occlusions environment - 10 sensors

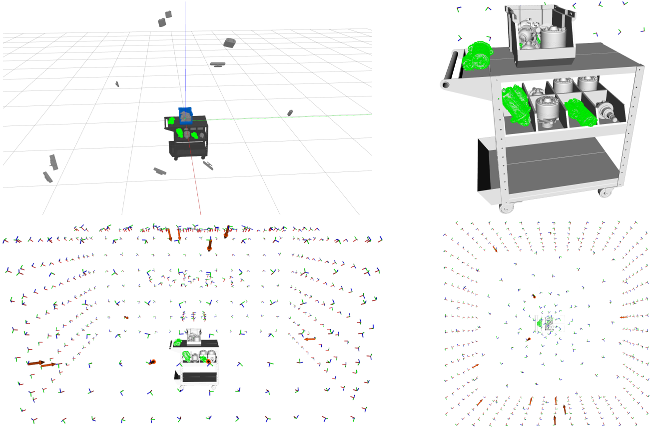

Fig. 16: Estimation of the 10 best sensors for the multiple bin picking with occlusions environment with a 44% of surface area coverage.

CONCLUSIONS

- The proposed system is able to estimate the N best sensors constellation for maximizing the observable surface area coverage for a given set of target objects.
- With a low sensor count the system can compute the best sensor constellation in less than a second, which makes it suitable for active perception tasks.
- Future work may include the testing of the proposed approach in conjunction with a object recognition system in order to reliably perform object tracking when an operator is manipulating a target object (by moving the sensor within the environment using a robotic arm).

Thank you!
Questions?