Autonomous 3D geometry reconstruction through robot-manipulated optical sensors

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Carmelo Mineo*, Donatella Cerniglia, Vito Ricotta

Department of Engineering, University of Palermo, Palermo (Italy)

* Marie-Curie Research Fellow (carmelo.mineo01@unipa.it)

UNIVERSITÀ DEGLI STUDI DI PALERMO

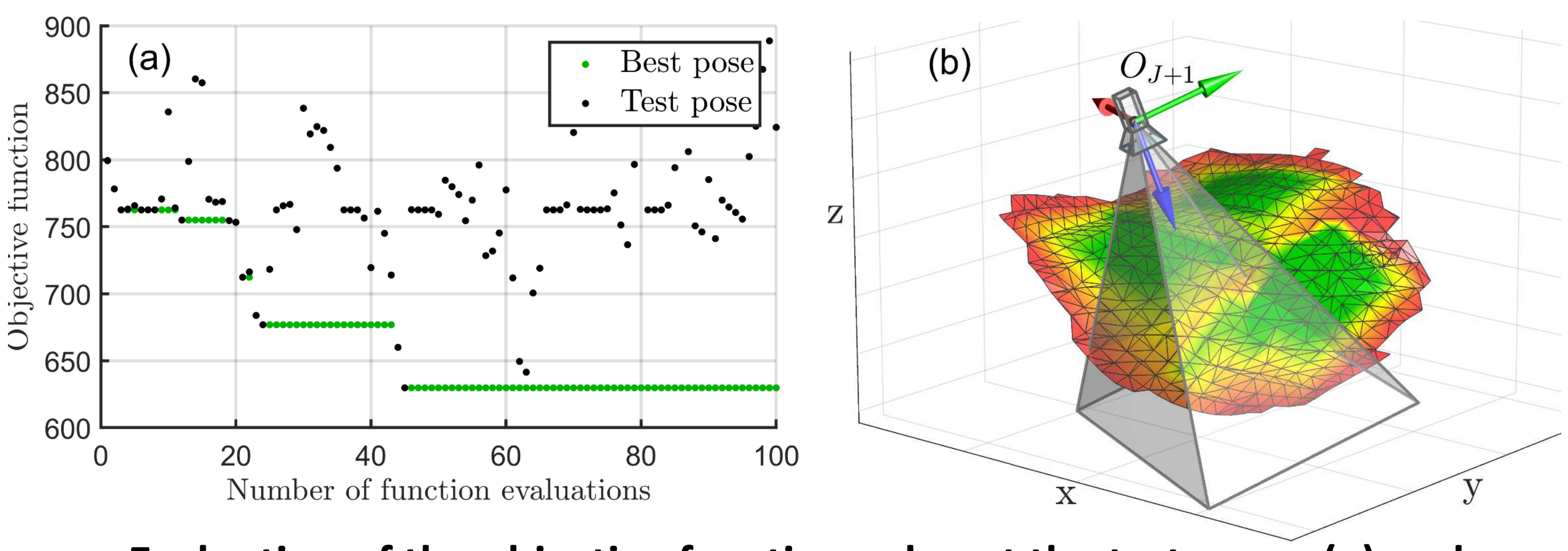
The use of robotics has increasingly penetrated the manufacturing and the construction industries. However the process of generating robot tool-paths, using simulation software, can be very time-consuming and an human intervention is often required to correct the software-generated robot paths. Promising approaches use computer vision to autonomously reconstruct the real workpiece geometry and automatically generate robot programs. The outcomes of the present research can play a pivotal role in the growing fields of smart manufacturing, industrial automation and Industry 4.0.

Research objectives

- Development of a mathematical framework for adaptive and incremental 3D reconstruction of specimens, through the use of a robot-manipulated optical 3D scanner;
- Computation of the next optimal view pose after each measurement view;
- Removal of the need to make a priori assumptions about the object shape;
- Validation of the method through measurable/quantitative results.

The steps of the developed method

1. A 3D-scanning sensor is mounted on a robotic manipulator;
2. The initial sensor view is acquired from a given pose;
3. A quality factor, namely *cumulative sampling density*, are computed for each point in the resulting point cloud;
4. The quality factor is used to evaluate an object function and find the optimum next sensor pose;
5. A new sensor view is acquired at the given pose;
6. The resulting new points are merged with the initial point cloud;
7. The process restarts from Step 3, until the stopping criteria are met.



Evaluation of the objective function value at the test poses (a) and illustration of the determined next best pose for the given example (b).

Results

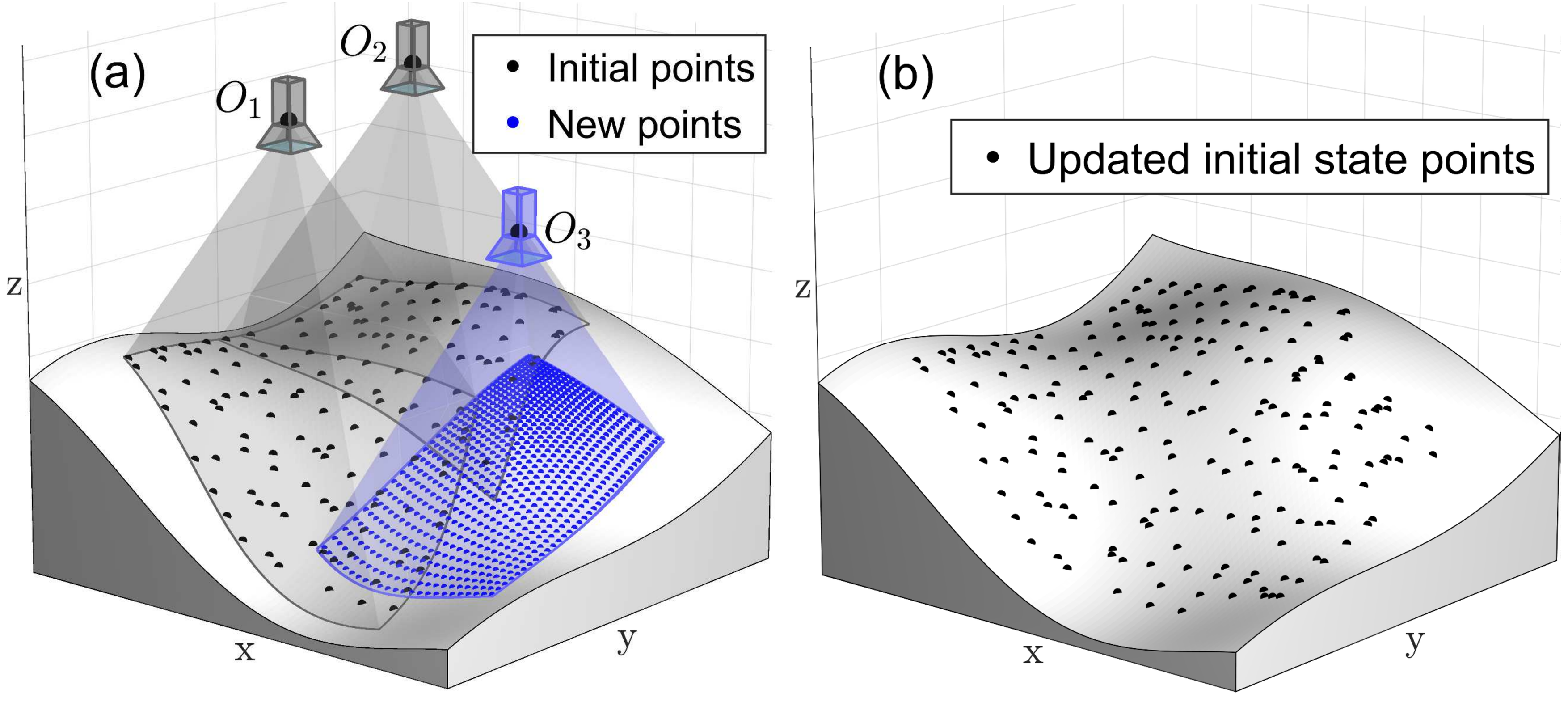
- The method allows efficient reconstruction of a given object using the minimum number of sensor views;
- Detailed method description published in open access journal paper, available at https://link.springer.com/article/10.1007/s00170-021-07432-5;
- The framework code is made publicly available, at https://doi.org/10.5281/zenodo.4646850, and can be used by the research community for future developments.

Used CAE software

- **MATLAB® R2020b** – for algorithm development, sensor control and robot control;
- **PolyWorks® 2015** – for geometry ground-truth acquisition;
- **CloudCompare v2 (open source)** – for generation of deviation maps.

Future work

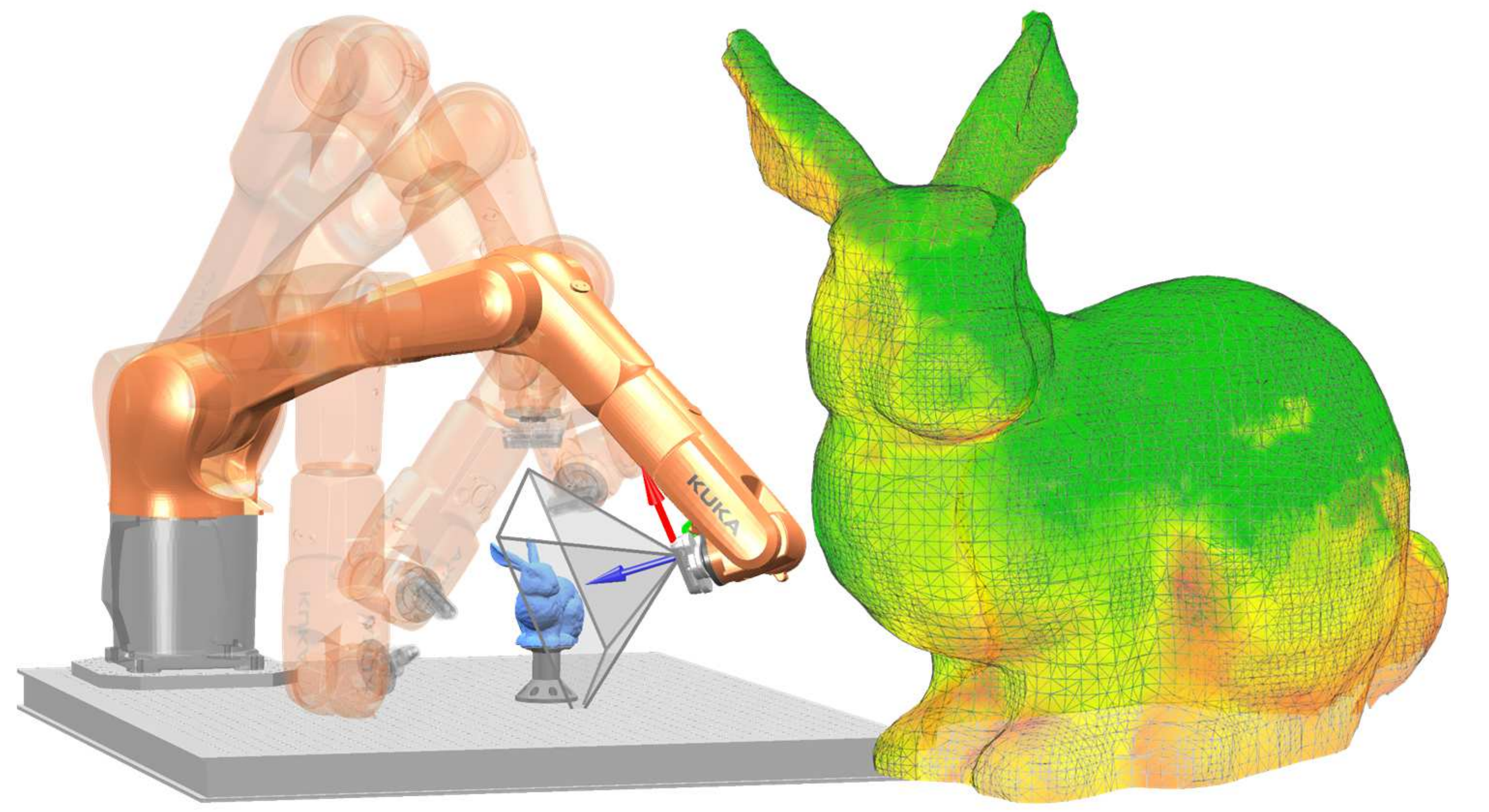
- Future work will focus on further enhancing the ability to deploy autonomously-generated poses corresponding to the absolute minimum of the objective function for all sampling steps.



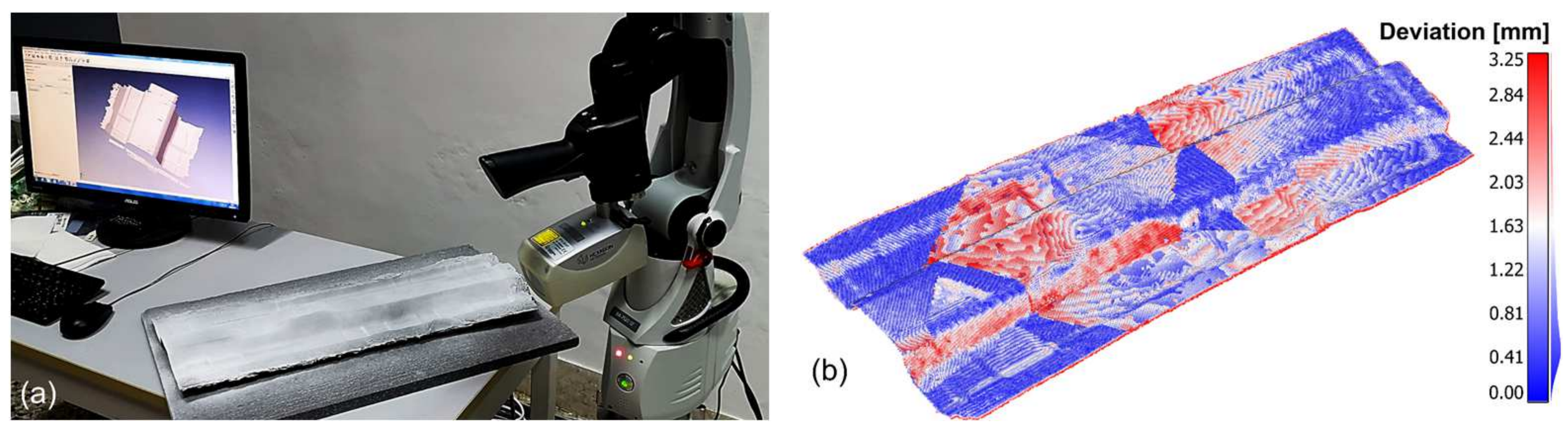
Initial state points and new incoming points (a). Resulting updated initial state, after merging (b).

Validation experiments

- Validation used simulated and real datasets;
- The experimental setup consisted of an Intel® RealSense™ Depth Camera D435i (an active 3D infrared stereo camera);
- The depth camera was manipulated through a KUKA KR10 robot;
- A MATLAB-based simulation environment was developed through integrating the virtual CAD model of the camera with the virtual model of the robot;
- An openly available machine-vision test model, known as Stanford Bunny, was chosen to benchmark the proposed autonomous mapping method;
- The method was also tested through an industrial specimen (a 4mm thick carbon fibre reinforced plastic curved shell sample).



Representation of incremental reconstruction of Stanford Bunny, through multiple autonomously generated camera views.



Acquisition of ground-truth point cloud through the Hexagon ROMER Absolute Arm (a). Map of deviation of the reconstructed geometry (b).

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