Robotized measurements : autonomous geometric and vibro-acoustic characterization of structures

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Introduction

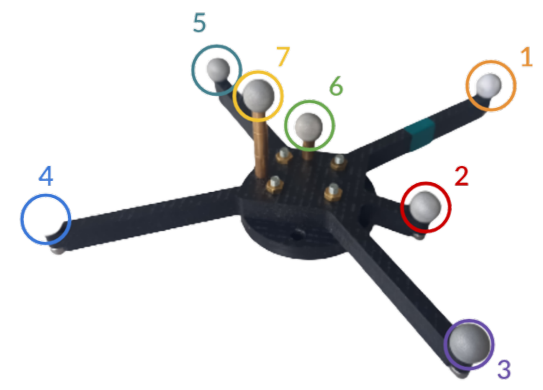
In the near future, robotics are to become an essential asset in the development of an ageing industry, by offering autonomous and reproducible means of manufacturing and production control. In particular, metrology operations, aiming to ensure the mechanical compliance and manufacturing quality of produced parts, are perfect candidates for automation. We propose an original and versatile robotic setup, able to perform both geometric and acoustic characterizations of unknown structures. This solution essentially relies on the use of a robotic arm, fitted with appropriate sensors, such as a depth camera, a single-point vibrometer or a measurement microphone.

Robotic arm absolute positioning precision

Absolute positioning precision assessment

In order to assess the absolute positioning precision of the robotic arm to be used, we opted for a multiple infrared cameras tracking tool - the *OptiTrack* - which provides the ability to measure the absolute position of spheric markers with a sub-millimetric accury.

As such an installation does not yield any information about the markers orientations, we conceived a rigid structure holding 7 markers, in a three dimensional and asymmetrical layout, in order to make up for this lack.



Using this so-called rigid body fixed on an UR10e robotic arm, two rounds of measurements were carried out using 100 randomly chosen learning configurations and 20 randomly picked testing configurations.

	Average absolute positioning error (m)	
	Learning error	Testing error
Without calibration	1,76.10^{-2} m	1,89.10^{-2} m
With calibration	2,25.10^{-3} m	2,03.10^{-3} m

Absolute positioning precision improvement

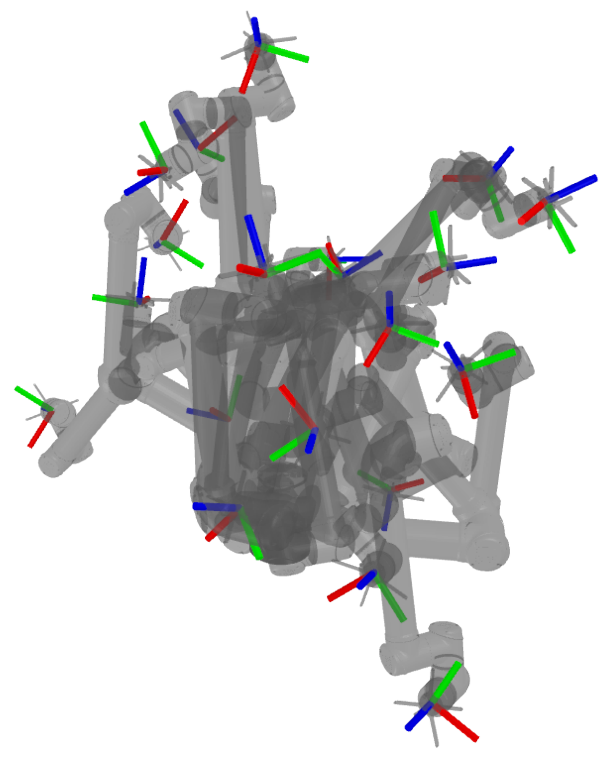
Given the poor absolute positioning precision of the robotic arm, and the significance of this aspect in order to obtain relevant metrology results, we designed the following hybrided calibration procedure :

1. **Geometric model definition** According to [1], build an *irreductible* and *complete* geometric model of the manipulator, which links the robotic arm configuration q to its end-effector position P, and highlights the seeked geometric parameters vector :
$$P(q, \pi) \text{ with } \pi = (\pi_{Base}, \pi_{Robot}, \pi_{Tool})$$
2. **Measurements design and implementation** Perform a sufficiently high number of position measurements N, according to a predefined learning set of configurations maximizing the parameters *identifiability* [2].
3. **Geometric parameters optimization** Following the Gauss-Newton method depicted in [3], compute an estimation of π minimizing the euclidian distance between the computed and measured absolute positions.

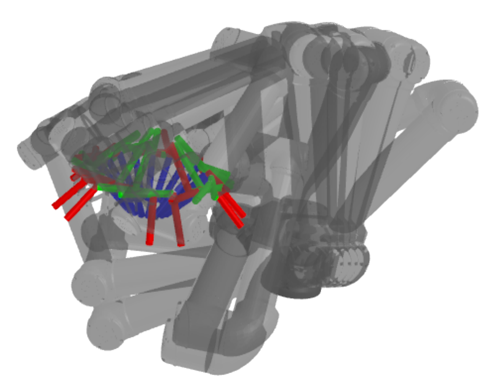
Implementing this procedure, the absolute positioning accuracy of the robotic arm was improved almost ten-fold. Yet, further improvements could be achieved with an enhanced measurements design optimization.

Measurements design optimization

Define a task-oriented configurations sampling space



Random sampling



Task-oriented sampling : spheric scan

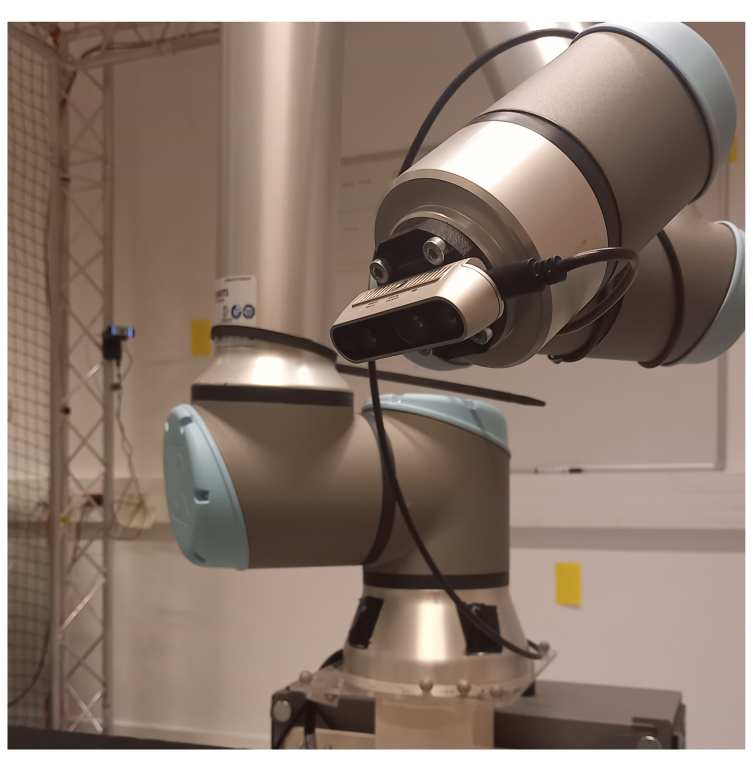
Focus more on precision, less on identifiability

Learning set definition	Identifiability metric	Precision increase
Random choice	0,644	89,27%
Simulated annealing	0,604	89,25%
Greedy permutations	0,640	88,88%
Genetic algorithm	0,653	85,16%

$\Longrightarrow$ A higher identifiability **does not always** guarantee a higher precision !

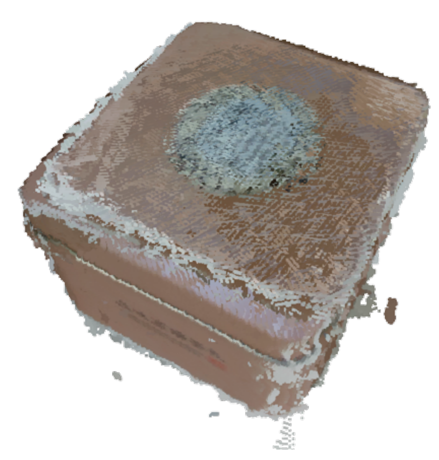
$$\underbrace{\max_{\substack{Q=\\q_1\dots q_N}} \mathrm{Tr}\left(\left(\frac{\partial P}{\partial \pi}^\top \frac{\partial P}{\partial \pi}\right)^{-1}\right)^{-1}\Bigg|_Q}_{\text{Usual A-optimality metric [3]}} \longrightarrow \underbrace{\max_{\substack{Q=\\q_1\dots q_N}} \mathrm{Tr}\left(\frac{\partial P^*}{\partial \pi}\left(\frac{\partial P}{\partial \pi}^\top \frac{\partial P}{\partial \pi}\right)^{-1}\frac{\partial P^*}{\partial \pi}^\top\right)^{-1}\Bigg|_Q}_{\text{Precision-oriented metric [2]}}$$

Geometric characterization



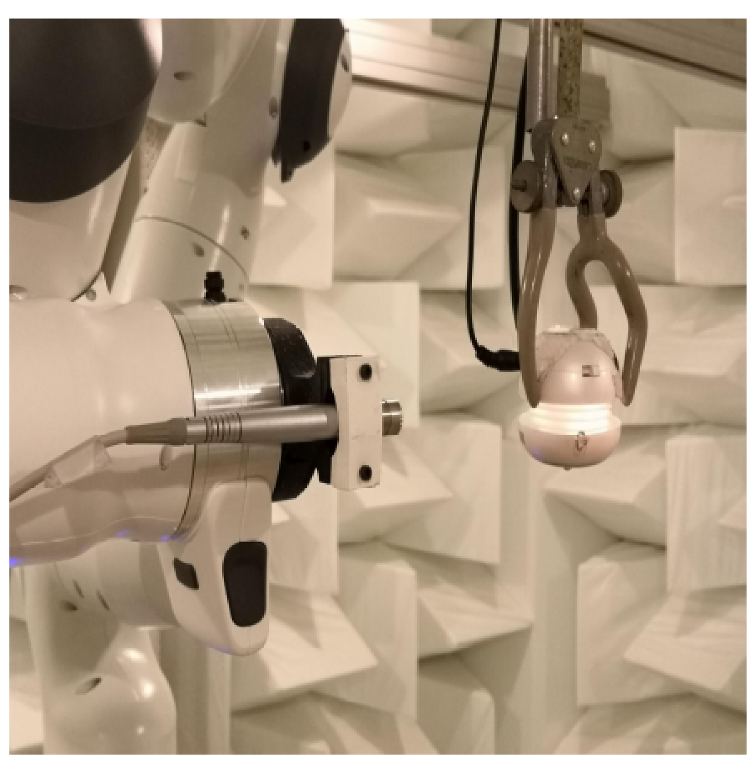
Depth camera setup

ICP matching

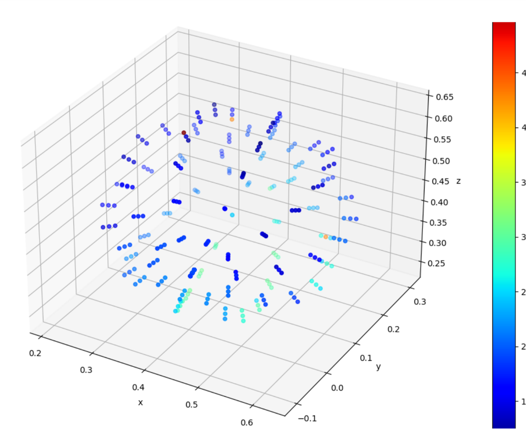


RTABMAP matching [5]

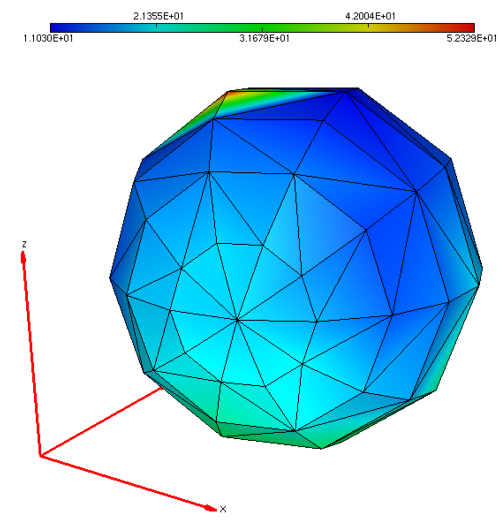
Acoustic characterization



Microphone setup



Raw pressure measurements



BEM based acoustic holography [4]

References

[1] A. Pashkevich, "Computer-aided generation of complete irreductible models for robotic manipulators", *3rd International Conference of Modeling and Simulation*, 2001.

[2] A. Klimchik et al., "Advanced robot calibration using partial pose measurements", *18th International Conference on Methods and Models in Automation and Robotics*, 2013.

[3] J. Alexandre dit Sandretto, "Certified calibration of parallel cable-driven robots", University of Nice Sophia Antipolis, France, 2013.

[4] Z.-W. Luo et al., "Near-field acoustic holography with three-dimensional scanning measurements", *Journal of Sound and Vibration*, 2019.

[5] M. Labbé et al., "RTAB-Map as an open-source lidar and visual simultaneouslocalization and mapping library for large-scale and long-term online operation", *Journal of Field Robotics*, 2019.

Perspectives

→ **Implement and evaluate new measurements design and parameters optimization methods** within the robotic arm calibration process;

→ **Improve and further automate both characterization processes** : post-processing, autonomous measurements definition and refinement, processes continuity, uncertainties integration, etc.