Positioning a cable-driven parallel robot at better than 0.25 mm using a multilateration system assisted by photogrammetry

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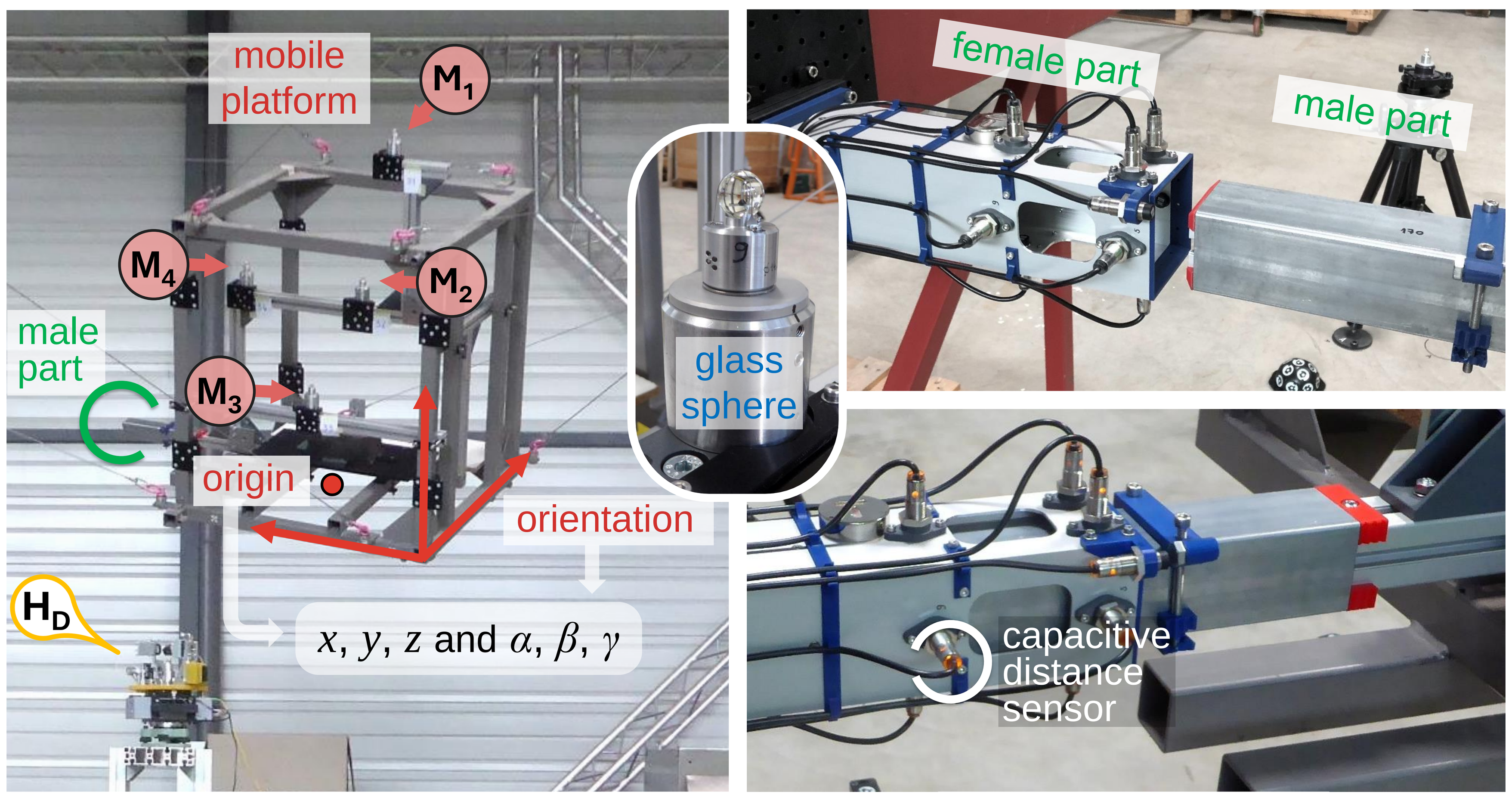
1. Cable-driven robot

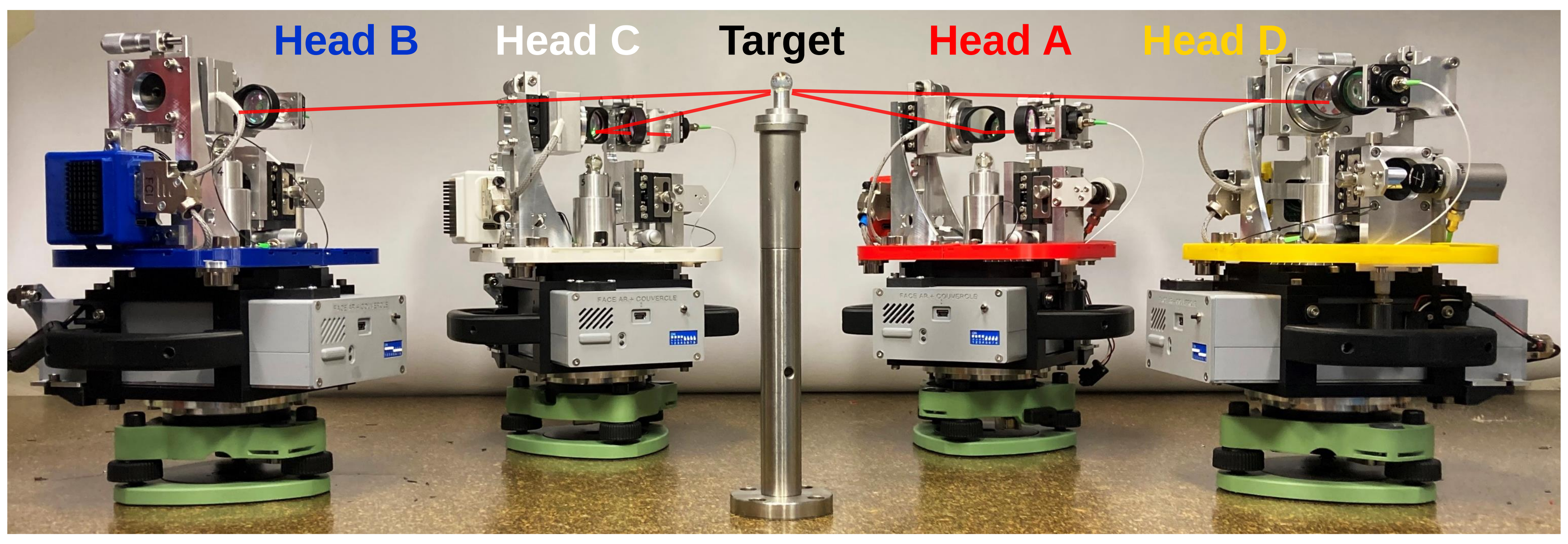
CoGiRo is a cable-driven parallel robot developed jointly by LIRMM and Tecnalia. It consists of a platform attached to the top of a structure by eight cables. Using motors, these cables move the platform across a large volume of 11 m × 15 m on the ground and 6 m high. The platform shown below weighs ~119 kg and can weigh up to 500 kg.



CoGiRo is not highly accurate, but it is highly resolute: the actual position of the platform is known to within a few millimetres, but it can be adjusted to within a few tens of micrometres. Its accuracy was improved using a multilateration-based coordinate measurement system developed by Cnam. This system measured the platform's poses (position + orientation) and reported to the cable-driven robot any errors it made so that it could correct them. This approach was tested in April 2024 with the aim of positioning the platform at better than 0.25 mm. A demonstrator was also set up, which consisted of inserting a square-shaped male part into a female part using the mobile platform. Capacitive sensors checked the distances between the two parts at ten positions: if the alignment was better than 0.25 mm at any of these points, an LED blinked. If the platform's pose was correct, all the ten LEDs blinked.

2. Cnam multilateration system

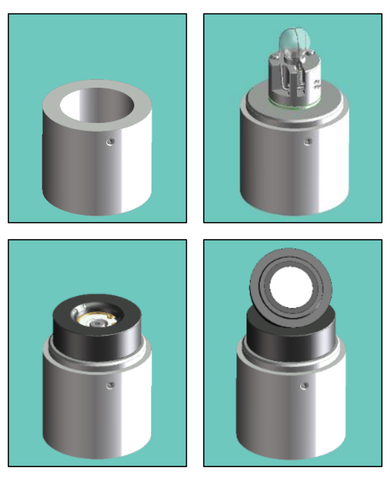
The Cnam multilateration system is based on a single Absolute Distance Meter connected to four measurement heads via optical fibres and an optical switch. It can measure distances with an uncertainty of about 5 µm (*k*=1) in a controlled environment. However, this system measures only static targets, such as glass spheres with a diameter of 14 mm and a glass refractive index of 2.
A multilateration technique with self-calibration was used to determine target positions from distance measurements. During the four-day measurement campaign, the main limitation was the stability of the head positions, which were not necessarily stable over time, especially for heads B and D mounted on large metallic structures that expanded with temperature. This resulted in a standard deviation of 13 µm between the measured distances and those derived from the estimated glass sphere positions.



At least three targets of a rigid body must be measured to determine a pose. In practice, four were installed on the mobile platform.

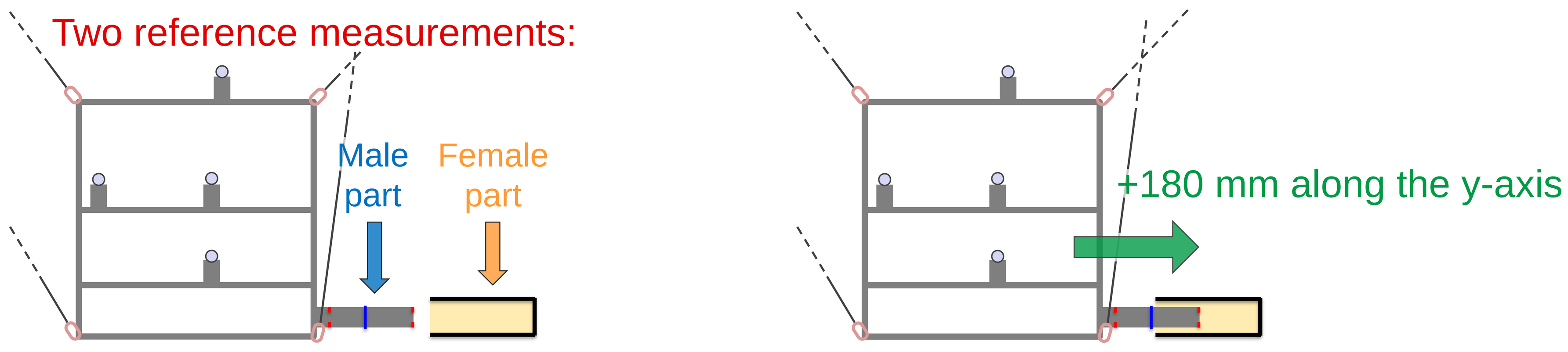
3. UCL and Ideko photogrammetric systems

UCL's four-camera photogrammetric system can track multiple targets in real time and provide their coordinates to within 0.5 mm. It helped the multilateration system to automatically orientate its measurement heads towards the spheres.
Ideko's single-camera photogrammetric system, called VSET, was used to calibrate the UCL's system. It surveyed all the photogrammetric targets installed in the workshop and on the platform at the start of the measurement campaign.
Eight common supports for the multilateration and photogrammetry targets were developed. These were first occupied by SMRs with a single retroreflective dot to be linked to permanent photogrammetric targets, then they were occupied by glass spheres to be measured by the multilateration system. In this way, it has been possible to build a common frame, and to know the positions of the spheres by photogrammetry.



4. Improving the positioning of the platform

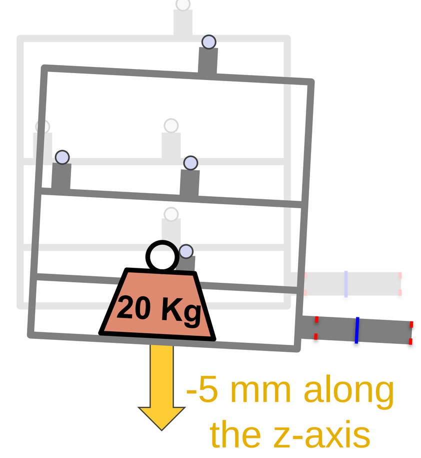
Two reference measurements:



1. An approach pose (AP): a position $P_{AP\,ref}$ and an orientation $O_{AP\,ref}$

2. A final pose (FP): a position $P_{FP\,ref}$ and an orientation $O_{FP\,ref}$

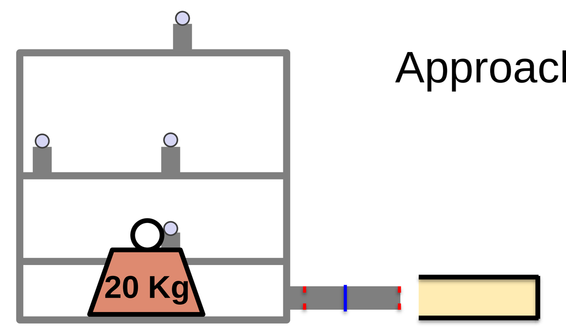
In the middle of the workspace, we added a 20 kg weight on the mobile platform.
The platform moved significantly, particularly along the z axis:



The pose was measured before and after the weight was added:
Position difference = – [0.630 0.933 5.218] mm
Orientation difference = – [1.607 -0.553 0.657] mrad

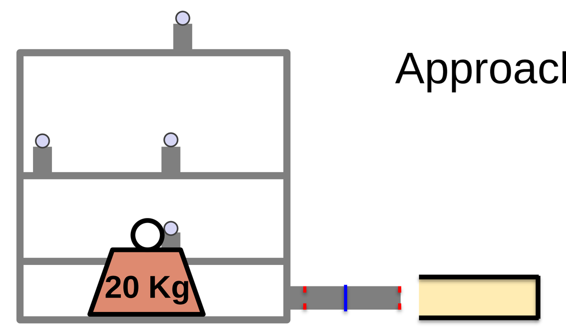
Adding a 20 kg weight changes the cable tensions.
In the 19 poses measured, the repositioning error is highly dependent on the localization of the platform. The error is smaller when the platform is close to the centre of the workspace.

Reproducibility test in the presence of the 20 kg weight:



Approach pose with the 20 kg weight

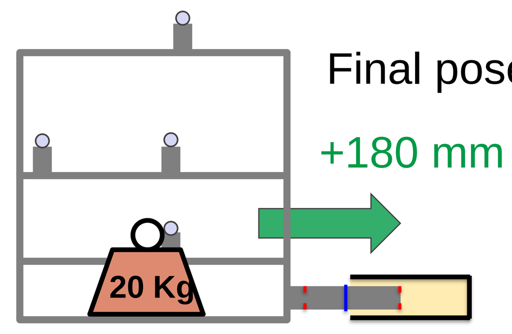
$P_{AP\,ref}$ – [0.355 0.222 7.274] mm
$O_{AP\,ref}$ – [0.722 0.065 0.071] mrad



Approach pose after multilateration-based correction

$P_{AP\,ref}$ – [0.007 -0.036 -0.015] mm
$O_{AP\,ref}$ – [0.052 0.052 -0.001] mrad

Positioning errors as low as 40 µm and 50 µrad !



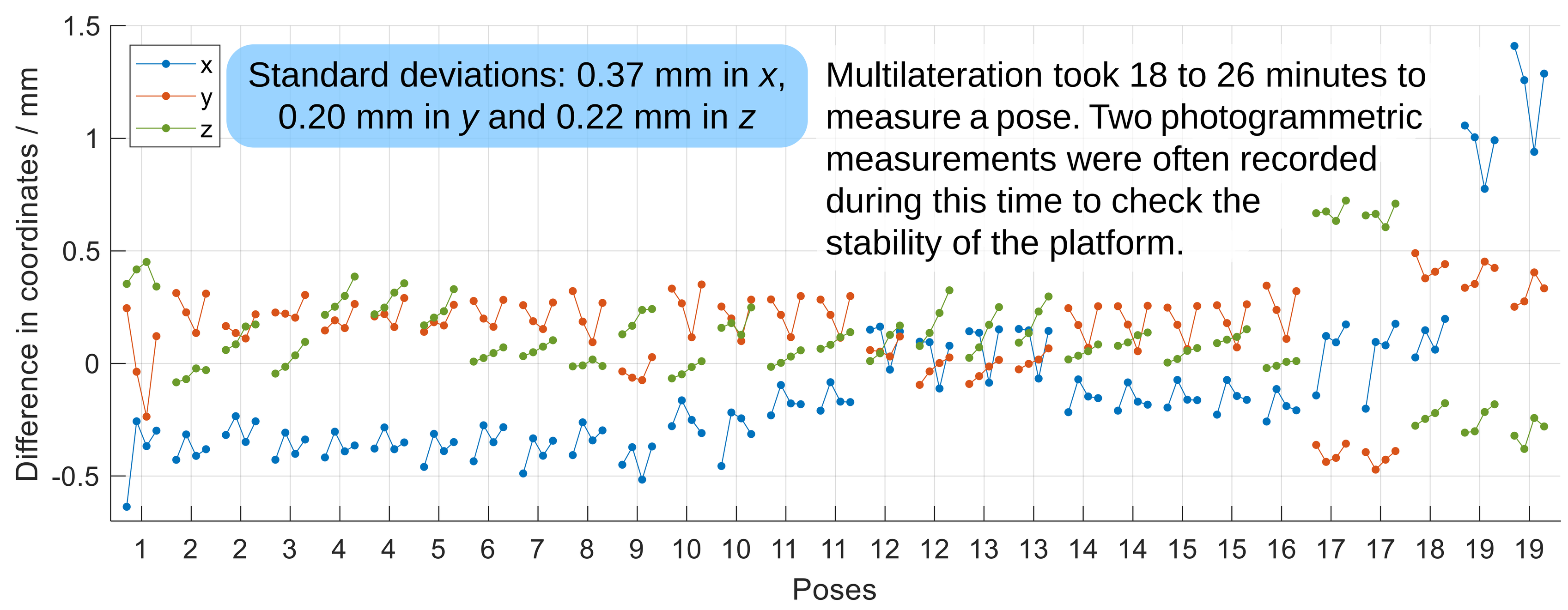
Final pose after a translation, and no additional correction

+180 mm

$P_{FP\,ref}$ + [0.019 0.041 0.374] mm
$O_{FP\,ref}$ + [-0.058 0.188 0.106] mrad

After a last correction of 374 µm in *z*, all the LEDs were blinking: the capacitive distance sensors agreed with the multilateration measurement, and the reproducibility of the pose was better than 250 µm.

5. Multilateration versus Photogrammetry



This intercomparison shows that multilateration and photogrammetric measurements were compatible to within 0.5 mm if we exclude the poses 17 to 19, which were outside the optimal measurement space for photogrammetry, i.e. too far from the cameras.

6. Conclusion

The use of a multilateration system has improved the accuracy of a cable-driven robot. After correction, positioning errors as low as 40 µm and 50 µrad were obtained. In addition, assembly of a male part into a female part at better than 0.25 mm has been successfully achieved and independently verified by capacitive distance sensors. Lastly, the comparison between multilateration and photogrammetry showed that photogrammetry could also be used to improve the robot accuracy to within 0.5 mm.

This work was partially funded by the Joint Research Project 20IND02 DynaMITE, which has received funding from the European Metrology Programme for Innovation and Research (EMPIR, funder ID 10.13039/100014132) co-financed by the participating states and from the European Union's Horizon 2020 research and innovation programme.

3D METROLOGY CONFERENCE
Loughborough, UK
September 24-26, 2024