Assessment of the mechanical uncertainties of a novel and affordable multilateration system

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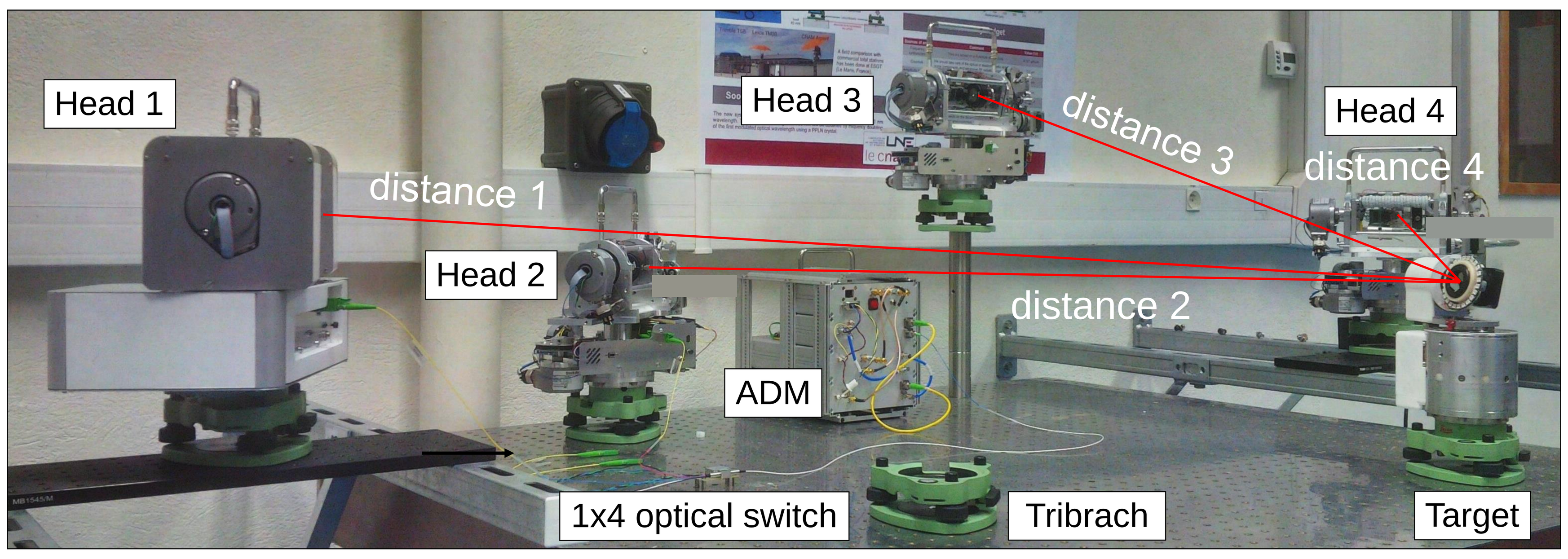
Multilateration system

The multilateration technique requires a large number of distance meters distributed throughout the space. To make this solution more attractive, novel distance meters able to bridge the gap between expensive but accurate laser trackers (or tracers) and cheaper but less accurate systems (indoor-GPS, photogrammetry) must emerge.

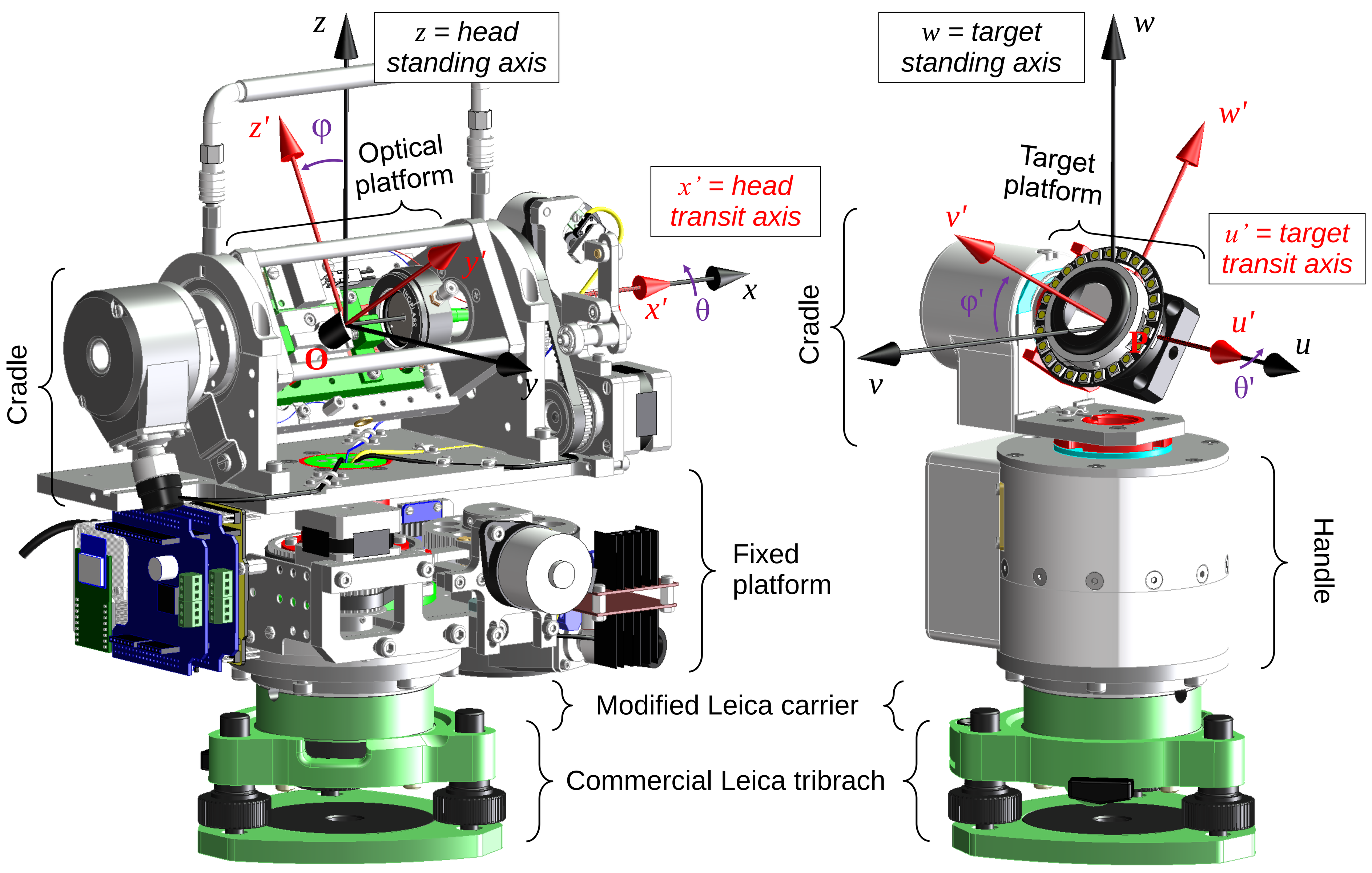
To this end, an Absolute Distance Meter (ADM) based on phase measurement of an amplitude-modulated light has been developed. It is used as a unique telemetric system that feeds different measurement heads through a network of optical fibres: the cost of the opto-electronic components is thus shared between the heads, which just play the roles of aiming devices. The target is a hollow corner cube.

The uncertainty contribution of the telemetric system itself is around 2 µm (k=1) for distances up to 100 m, which leave us a considerable latitude for other sources of error.

Our objective is a position accuracy better than 50 µm (k=1). What is the impact of the mechanical designs of our heads and of our target on the global uncertainty ?



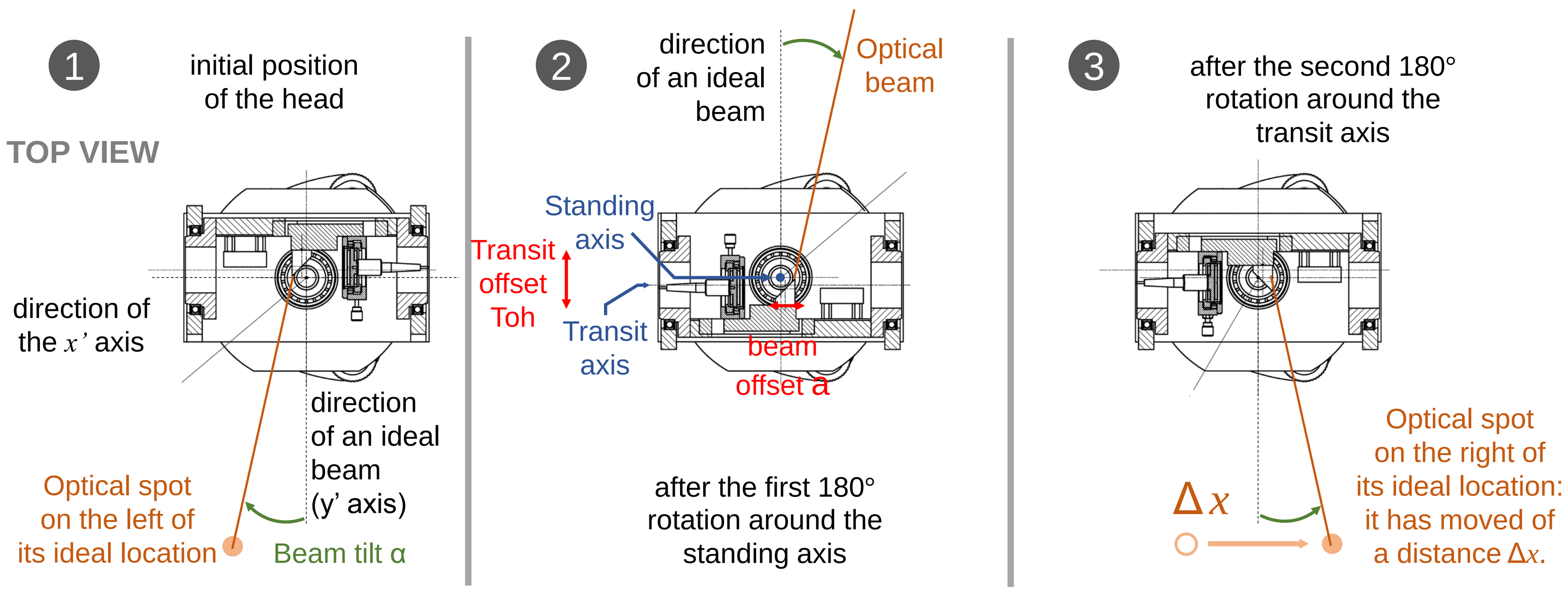
3D-view of the developed devices



For perfect distance measurements, the laser beam should pass by the intersection of the two rotation axes of the head, in O, and the corner cube should be placed at the intersection of the two rotation axes of its gimbal mechanism, at the point P.

Determination of the errors

To characterize the misalignment of the gimbal mechanism of the measurement head, a double-centering is achieved. This consists in pointing the same object under two different positions thanks to a first rotation of 180° around the standing axis, then a second 180° rotation around the transit axis.

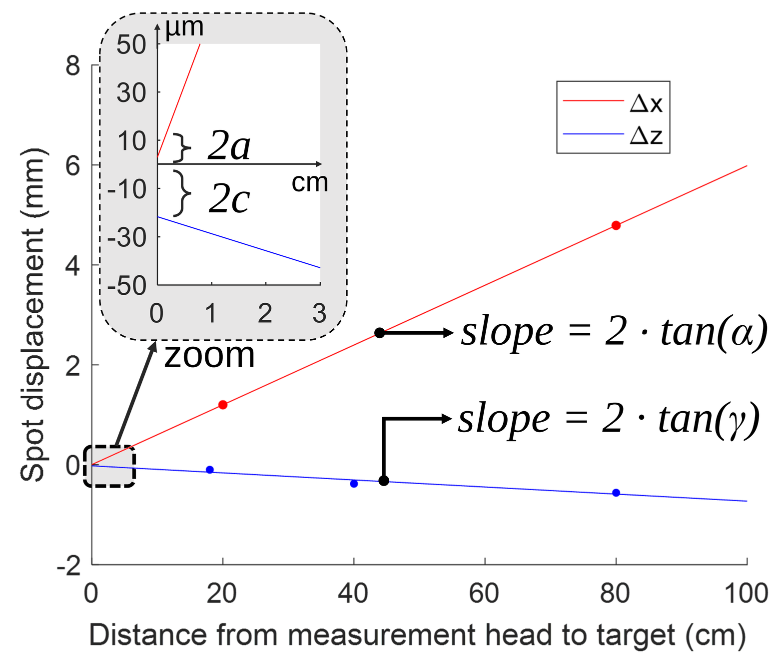


The displacements of the beam spot Δx and Δz after double-centering as a function of the distance provides the tilt angles and the beam offsets. The half distance difference between measurements before and after double-centering gives the transit offset.

The transit offset of the target is obtained in the same manner as the heads.

Lastly, to determine the values a', b', and c' of the target offsets, we minimize the difference between the established error model and the variations of the error measured on a fixed distance as a function of the viewing angles θ' and φ'.

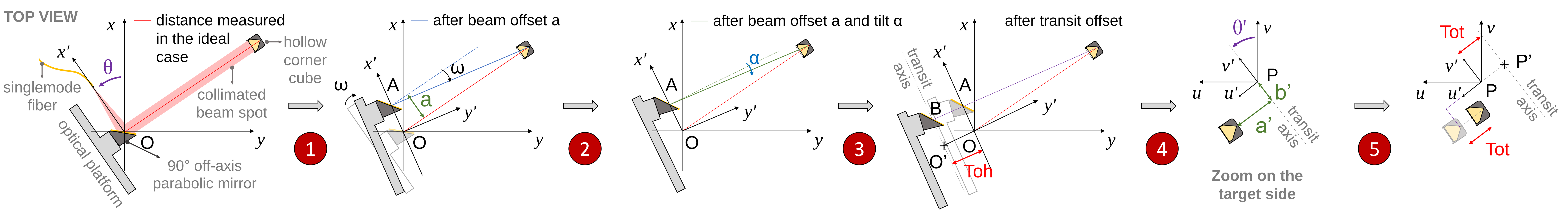
The positions of the parabolic mirror and of the corner cube, as well as the transit axes, have been mechanically adjusted after first measurements to minimize the errors, which was possible thanks to translation stages.



Uncertainty budget (Head 1 and Target)

Parameters	Description	Sources	Measured values	Error induced on the distance
1 a and c	Beam offset	misalignment of the gimbal mechanism of the measurement head	1.5 and -10.6 µm ± 60 µm	error < 250 nm
2 α and γ	Beam tilt		0.171° and 0.017° ± 0.005°	
3 Toh	Transit offset of the head		3 µm ± 2 µm	< 2 µm after Toh correction
4 a', b', c'	Target offset	misalignment of the gimbal mechanism of the target	-6 µm, 29 µm, and -22 µm	error < 9 µm
5 Tot	Transit offset of the target		11 µm ± 2 µm	< 2 µm after Tot correction
6 Do	Distance offset (no impact for multilateration)	difference between the measured distance and the mechanical one	not measured	can be corrected
7 Pe or ω_p	Pointing error	Limited resolution of the pointing system	550 µm and 400 µrad	0 µm

List of the geometric misalignments of the gimbal mechanisms



1. Beam offset: the laser beam may be displaced from its ideal position by constant offsets a and c on the x' and z' axes, respectively.

2. Beam tilt: the laser beam may also be tilted from its ideal path, i.e. it may be not normal to the x' O z' plan with angles α and γ, respectively.

3. Transit offset on the measurement head: the transit axis may not intersect the standing axis due to a translation Toh from its ideal location.

4. Target offset: the corner cube may be displaced from its ideal position by the offsets a', b' and c' on the u', v' and w' axes, respectively.

5. Transit offset on the target: the transit axis may not intersect the standing axis due to a translation Tot from its ideal location.

➡ Finally, an error model is established, i.e. the difference between the real distance and the measured one, a function of the variables a, c, α ,γ, Toh, a', b', c', and Tot.

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