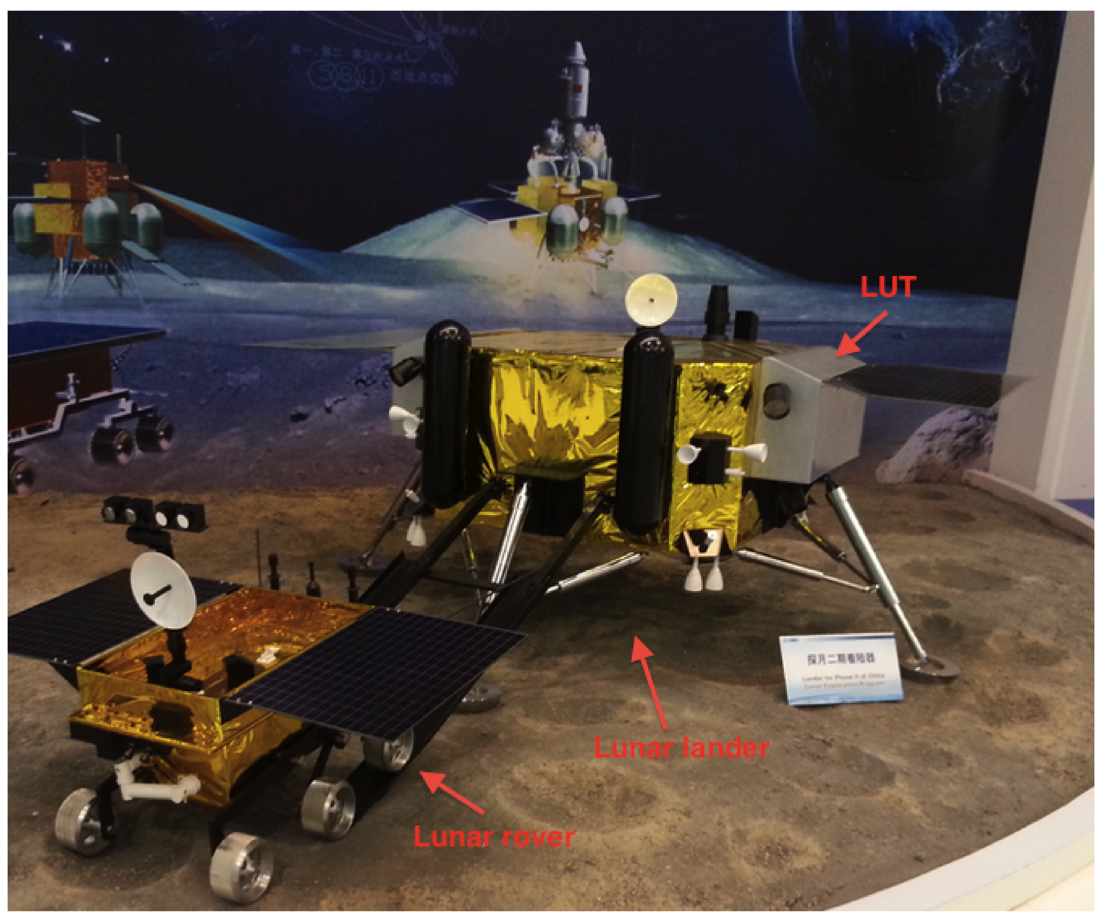
Astrometric Support for LUT

Zhaoxiang Qi†, Yong Yu, Zhenghong Tang and Ming Zhao
Shanghai Astronomical Observatory, Chinese Academy of Sciences
†kevin@shao.ac.cn

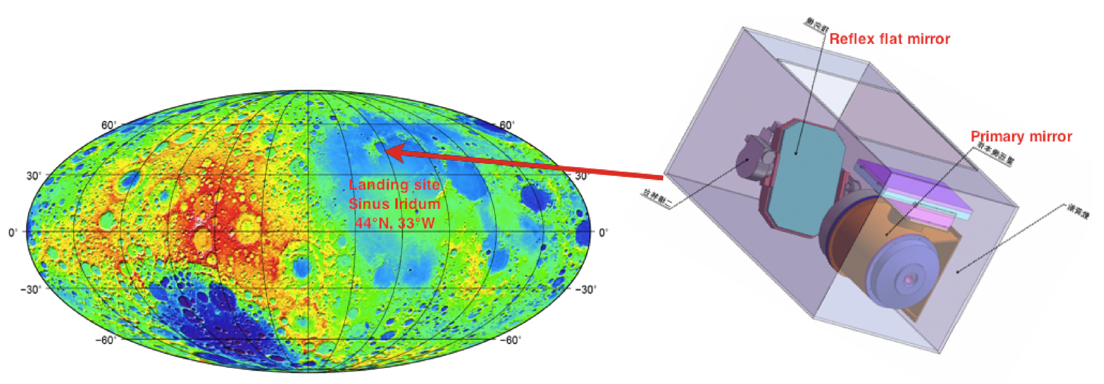
LUT

The Lunar-based Ultraviolet Telescope (LUT) is an astronomical instruments of Chang′e 3 – a lunar probe of the China Lunar exploration programme, which is scheduled be launched in late 2013. LUT will be the first robotic sky survey telescope landed on the Moon, and will chart an ultraviolet map of the plane of the Milky Way, on top of that, it will do long-term light variation monitoring for some celestial objects.



This figure shows the display model of Chang′e 3 lunar probe. LUT is mounted on the Lunar lander, which will land at Sinus Iridum.

The optical system of LUT is an F/3.75 *Ritchey – Chrétien* telescope with an aperture of 15 cm and 1.36 degree field of view. A reflex pointing flat mirror that is mounted on a two-dimensional gimbal is used to point and track the preferred objects. An ultraviolet-enhanced CCD detector is mounted at the Nasmyth focus with the scale 4.8 arcsec/pixel. A limiting magnitude of AB=13 mag is designed for an exposure time of 30 seconds.



This figure shows the Optical schematic of LUT and its site on the topographic map of moon.

PROBLEMS

⊗ The Lunar lander on which LUT will be mounted is unmanned and will land under computer controlling. So theoretically the touch down could occur anywhere at any attitudes. The accurate position and the attitudes are unable to be known. Reference to the case of conventional ground-based observations, there make the pointing and tracking for the wanted celestial objects impossible.

⊗ Moreover, to reduce the transmission load, people could not download the whole frame for every exposure while could only download the image data surround the objects, which people should know the accurate position and velocity of the object on the CCD.

⊗ LUT is using a reflex flat mirror for pointing, which is quite different from the conventional telescope.

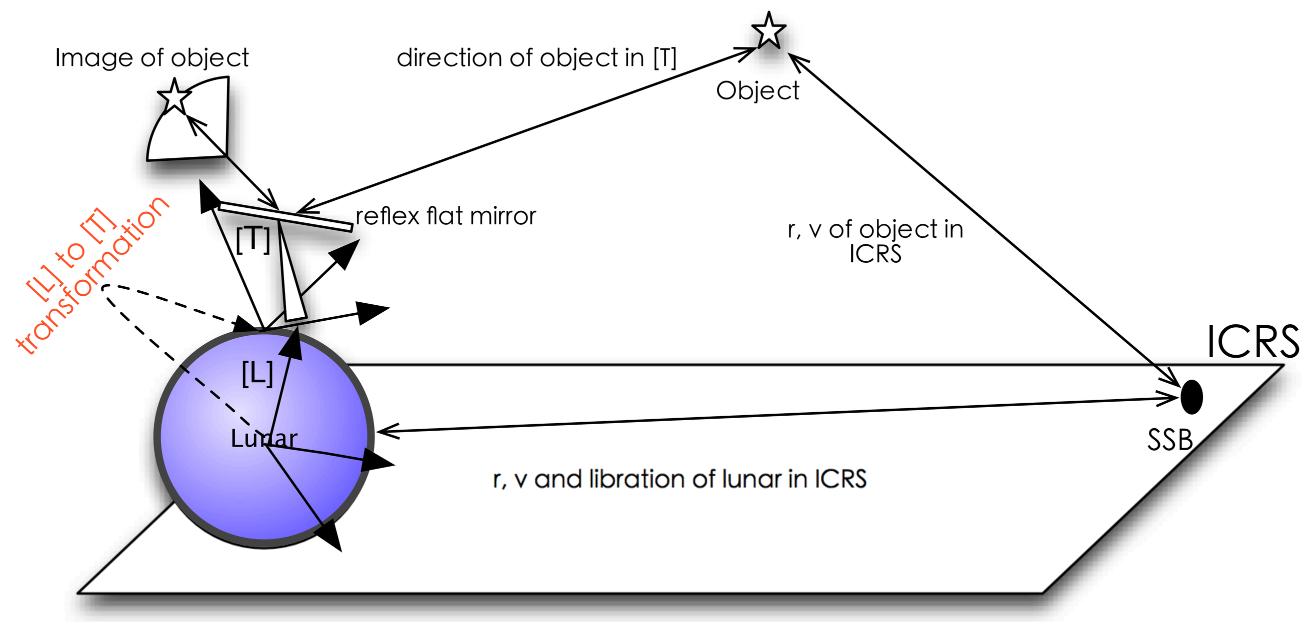
CONTRIBUTONS

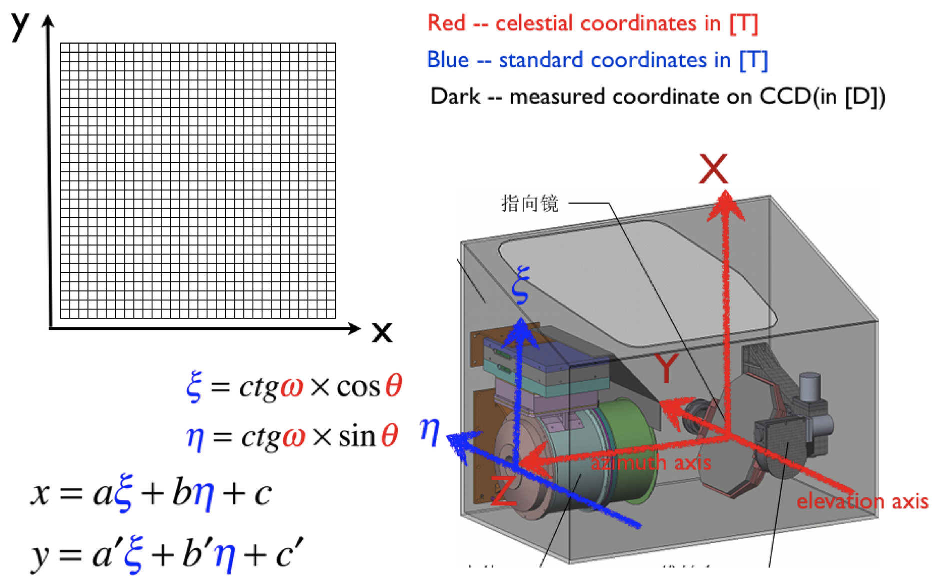
The great efforts have been devoted to calibrate the basic information (altitudes, CCD constants etc.) of LUT for the accurate pointing and tracking of celestial objects and targets detecting on CCD images via a new astrometric process and associated method. Some ground verifications have verified the reliability of the new astrometric solution, which will be a well-tested resolvent for LUT.

We could imagine that the ideas and the relative softwares will have a wide applicable prospect. It can be used for automatically calibrating the altitudes of ground-based telescopes (including both the movable and stationary telescopes) related to its local Horizon coordinate system or/and related to ITRF(International Terrestrial Reference Frame) without any manual operations or other technical supports. It could also be applied to telescopes planning to be launched onto other planets.

SOLUTIONS

For pointing and tracking the wanted objects, the relationship between ICRS and LUT body-fixed coordinate system (hereafter [T]) should be known accurately (The following figure on the left shows the relationships.).

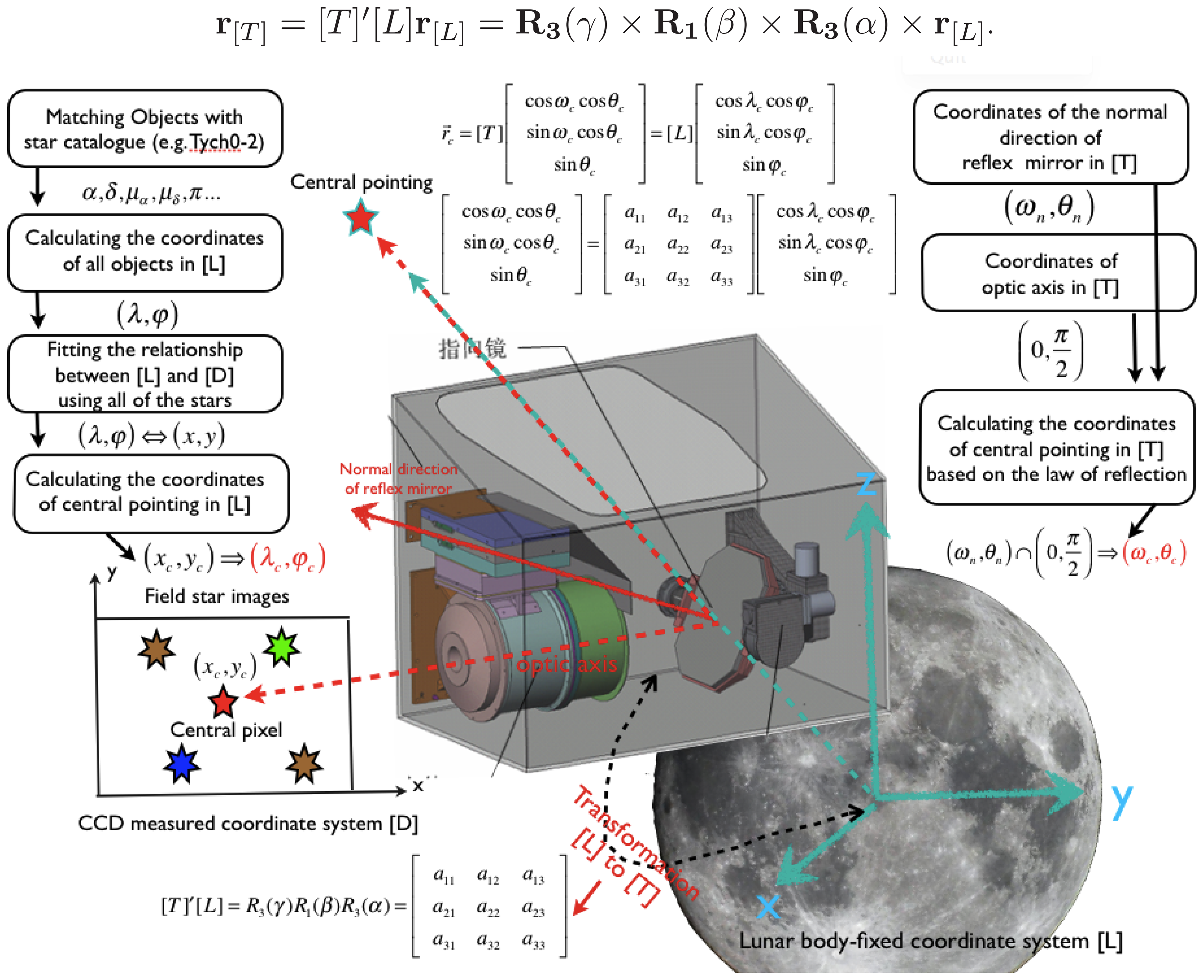




The conventional process for Lunar-based observations is to firstly take the space motion of object into account and following with parallax, light deflection by the Sun and aberration, then get the result being expressed in Lunar-Centric Celestial Reference System (LCRS, shares the same orientation with ICRS). Next reckon the rotation of moon by using its libration, the results will be expressed in the Lunar body-fixed coordinate system (hereafter [L]). [All the transformation parameters related with moon (position, velocity and libration of moon in ICRS) could be accurately known in advance from the Jet Propulsion Laboratory (JPL) ephemeris (e.g. DE421), and for the object's parameters(α, δ, μ_α, μ_δ, π, $\dot{r}$) could get from its catalogue. People could use the conventional astrometric process to take these effects into account, so we will not go into detail.]

The most important work next is how to perform the transformation from Lunar body-fixed coordinate system [L] to [T]. Since LUT is fixed on the Moon, our solution is to directly establish links between the [T] and [L] by using three Euler angles only. And to avoid the "Gimbal lock" problem and having several valid solutions for one Euler angle problem, we actually fit the nine elements in the final rotation matrix $[T]'[L]$ but not those three Euler angle. The astrometric process and associated formulas are as following

$$\mathbf{r}_{[T]} = [T]'[L]\mathbf{r}_{[L]} = \mathbf{R_3}(\gamma) \times \mathbf{R_1}(\beta) \times \mathbf{R_3}(\alpha) \times \mathbf{r}_{[L]}.$$



To achieve only downloading the CCD data surround the object image, the relationship between object's spherical coordinates $[\omega, \theta]$ in [T] and its measured coordinates $[x, y]$ in CCD measured coordinate system (hereafter [D]) should be known (The figure on the top right corner of this poster shows their relationships and the related coordinate systems.).

The CCD is mounted on the telescope, so the relationship between them should be fixed. With the fitted rotation matrix $[T]'[L]$ above, the spherical coordinates $[\omega, \theta]$ in [L] of all the field stars (as reference points) could be calculated, and together with their measured coordinates $[x, y]$ in [D], we could fit out the transformations between [L] and [D] via the classical photographic astrometry techniques. But here we perform them in a different way, by defining the the standard tangent plane perpendicular to the optical axis of LUT (That is the Z axis of [T]), and the ξ and η axis as the same direction as X and Y axis of [T]. Using the gnomonic projection, the equations of the transformation from spherical coordinates $[\omega, \theta]$ to their standard coordinates ξ and η are as showed on the top right corner figure. Considering the required precision for object detection is around tens of arc-sec (e.g. several pixels), here we model the CCD only with the first-order polynomials and ignore all the other small terms.

PROCESS

The general process of Astrometric Support for LUT is as follows

⊕ Taking at least 3×3 images evenly divided in its visible sky;

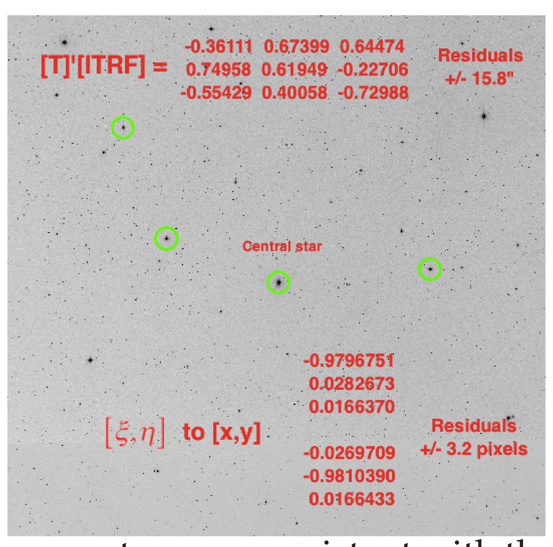
⊕ Doing the data reduction to calibrate all the unknown parameters (e.g. [L] to [T] and $[\xi, \eta]$ to [x,y]);

⊕ Calculating the available observation period the tracking ephemeris and the coordinates on CCD of the wanted objects;

⊕ Sending these data to the Telescope Control System for performing the sky survey observation.

VERIFICATIONS

We have done some experiments in the past two years on the ground by simulating the situation of LUT on Lunar (putting the telescope on the ground with random altitudes) to verify the reliability of our new astrometric solutions. The right figure shows the results from one experiment taken at Nov 24, 2011.



The residuals of the calibrated parameters are consistent with the optimal accuracy of the hardwares and all the 4 wanted stars fell on the predetermined positions (marked with the bright green circles).