MLRO System Progress Report

Presented at the Eleventh International Workshop on Laser Ranging

Deggendorf, Germany 21-25 September 1998

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Abstract:

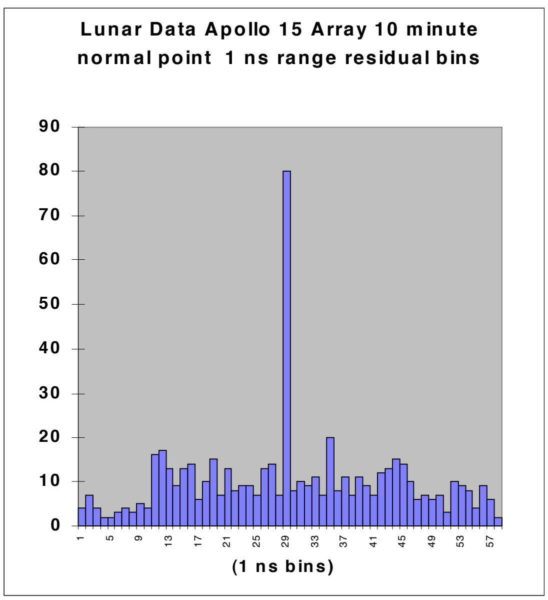
The Matera Laser Ranging Observatory (MLRO) system has been under development since mid 1995 – after its critical design approval. The single-color system was essentially completed in mid 1998 and began collocation in August 1998. This paper provides an overview of recent MLRO development milestones and presents results from its collocation.

The MLRO system has been under development since June 1995 after the successful completion of its critical design review. Prior to this development, the long-lead item development occurred. These long-lead items included the laser and telescope, both of which were completed in 1995.

After the subsystem development phase, which was largely performed in the AlliedSignal laboratories, the system elements were moved into the recently refurbished STALAS facility for integration in March 1997. The MLRO received its first satellite returns in April 1997 on its first attempt using a Glonass satellite and began tracking satellites on a routine basis under engineering status. By June 1997, the MLRO was recording 5.5 millimeter single shot data using the LAGEOS satellites and an almost 100% return-rate. The MLRO uses an MCP-PMT / oxford discriminator combination to detect the satellite returns and the ATSC-developed event timer to record time-tags for range measurement. The first six-months of data did not employ any special calibration techniques (for amplitude or the event timer).

Once we were satisfied that the system could track satellites without difficulties, we began to focus our efforts on acquiring lunar data. ATSC had received software algorithms from Dr. Veillett (of CERGA) and adapted these into the MLRO software system. The process of making this work, coupled with our first attempts at Lunar ranging took a few months to accomplish. We had been fortunate to have Peter Shelus and Randy Ricklefs invite our team to participate with the MLRS team in tracking Lunar targets at Ft. Davis for a few days. This provided us with valuable operational experience and helped us acquire and recognize our first lunar data at GGAO in Greenbelt Maryland. The MLRO's first lunar data was acquired in February 1998. The MLRO was able to repeat these measurements on several occasions, including under daylight conditions.

Figure 1 shows a sample lunar ranging data set for the MLRO from Greenbelt Maryland. The left plot is a histogram of a single normal-point. By the CERGA convention, lunar ranging normal points are each 10 minutes in duration. The right-hand plot shows an O-C plot for all of the lunar normal points acquired during one session. The last few normal point data was acquired after sunrise. The curve to the data is caused by uncertainty in the predictions.



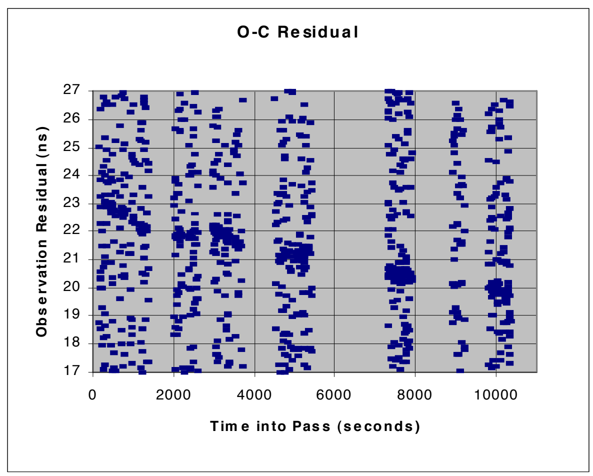


Figure 1: Lunar Ranging Data Set Sample

Once we were satisfied that the system could routinely track lunar targets, we began preparations for the MLRO – MOBLAS-7 collocation. These preparations included incorporating the event timer calibration data and discriminator (amplitude-dependent) calibrations for both transmit and receive channels.

The MLRO collocation plan had been submitted and approved by the ASI in 1993. It required very high performance from the MLRO system for each data set. Some of these conditions included:

- Daylight and nighttime stability tests of at least 1 hour each, with system stability < 1mm.
- Calibration RMS < 3mm, pre to post pass system delay shift < 2.5mm for all passes. The shift would normally be < 1 mm but continuous air conditioner problems at the STALAS building caused extreme variations in the room temperature affecting the hardware stability slightly.
- Agreement with MOBLAS-7 for all passes with < 10mm and <10mm bias drift within any pass for at least 30 LAGEOS passes and 20 other passes. Full-rate data (single shot) for LAGEOS passes ≅ 5mm or better.
- Signal strength calibration target data < 1mm.
- Azimuth and Elevation dependency < 1mm.
- Full sky coverage, ascending and descending modes.
- Quite a number of other related tests, all with 1 mm – level performance.

The collocation requirements were more strict for the MLRO than any previous collocation and would require that both the MLRO and the MOBLAS-7 systems each perform their best for a successful collocation. The MOBLAS-7 system requirements were not as strict as the MLRO requirements, but deviations in system stability could manifest themselves as a bias, which would reflect on the performance of both systems.

Collocation Results

Stability Tests

Figure 2 and Figure 3 display the results of a day and night stability test performed by both systems during the collocation period. The peak-to-peak delay shifts are 0.38 and 0.69 mm respectively. The MLRO stability tests were required to exhibit less than 1 mm peak-to-peak. A typical NASA collocation requirement is 5mm.

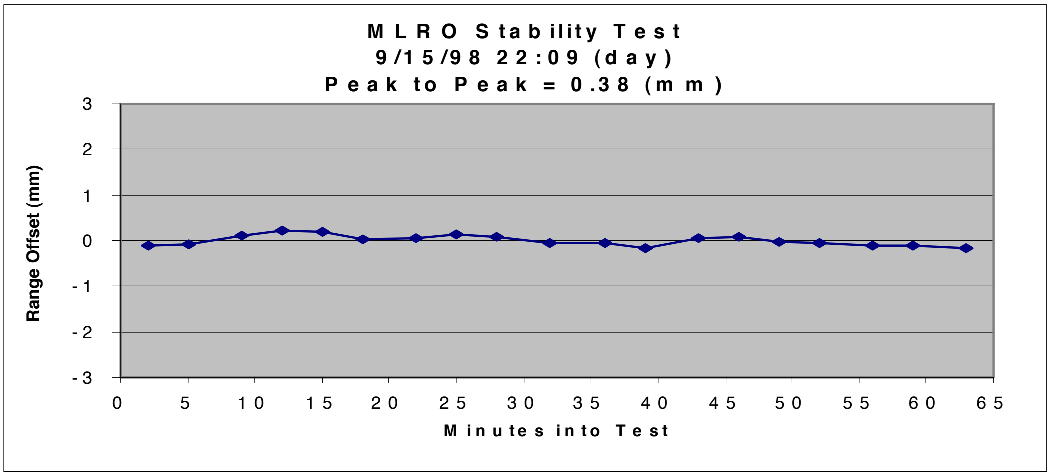


Figure 2: Sample Daylight Stability Test

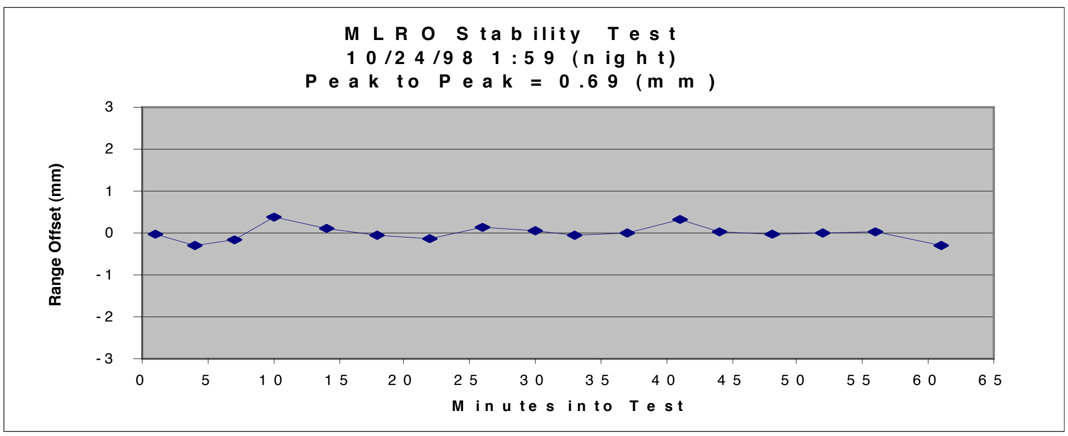


Figure 3: Sample Nighttime Stability Test

Calibrations for Satellite Passes

The MLRO requirements called for a single-shot RMS of less than 3 mm for ground targets. Calibration delay shifts were typically less than 1 mm (peak-to-peak) for collocated passes. The MLRO system typically obtains a single-shot RMS of approximately 1mm for ground targets. The range is typically from 0.8mm to 1.2 mm RMS. A sample calibration file is shown in Figure 4.

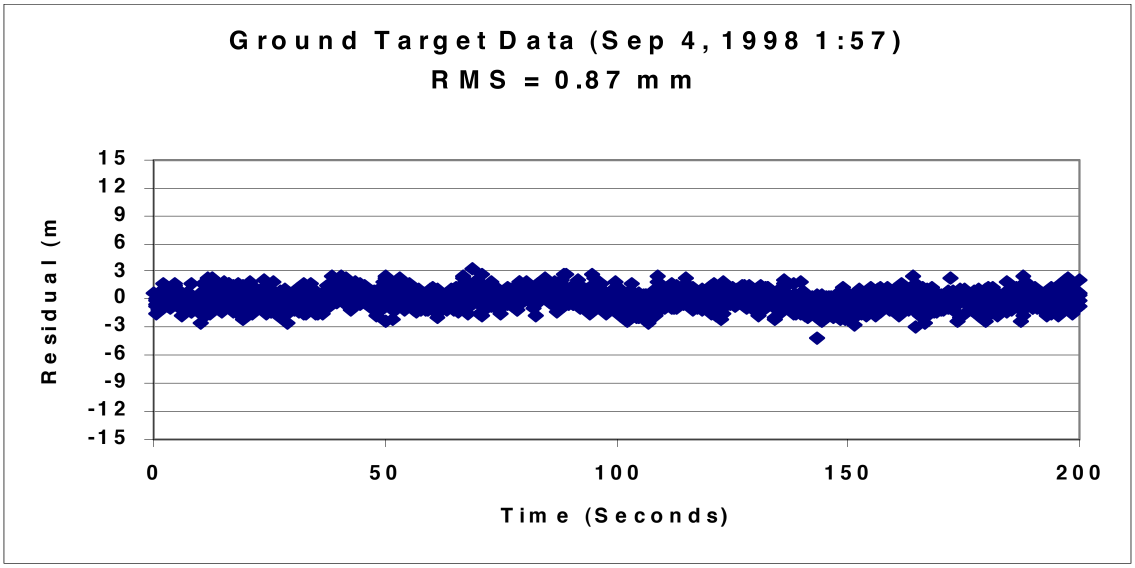


Figure 4: Sample Scatter Plot for an MLRO Calibration Target File

Satellite Data

The most important satellites tracked for collocation are the LAGEOS 1 and LAGEOS 2 satellites. Figure 5 shows a scatter plot of normal points for all qualifying LAGEOS and LAGEOS 2 collocated passes. The qualification is based on both the MLRO and MOBLAS-7 systems performance and to qualify there was a minimum overlapping normal point requirement. It was not always possible to qualify every pass since MOBLAS-7 could not always acquire data from the satellite due to poor atmospheric conditions. Since the MLRO typically uses a neutral density filter wheel during LAGEOS ranging, often using a 1 ND filter, the system could track satellites during even very bad atmospheric conditions. The figure also illustrated a suspected survey error between the two-system's center of rotation by the slight sinusoidal azimuth-dependent pattern. The MLRO used its internal calibration assembly to verify that the pattern was caused by a physical mechanism outside of the MLRO system. This survey shift for MOBLAS-7 was confirmed in the post-collocation survey. The post-collocation survey also confirmed that one of the ground targets had shifted by 5 mm. Both systems accurately recorded the shift during Minico ground target tests.

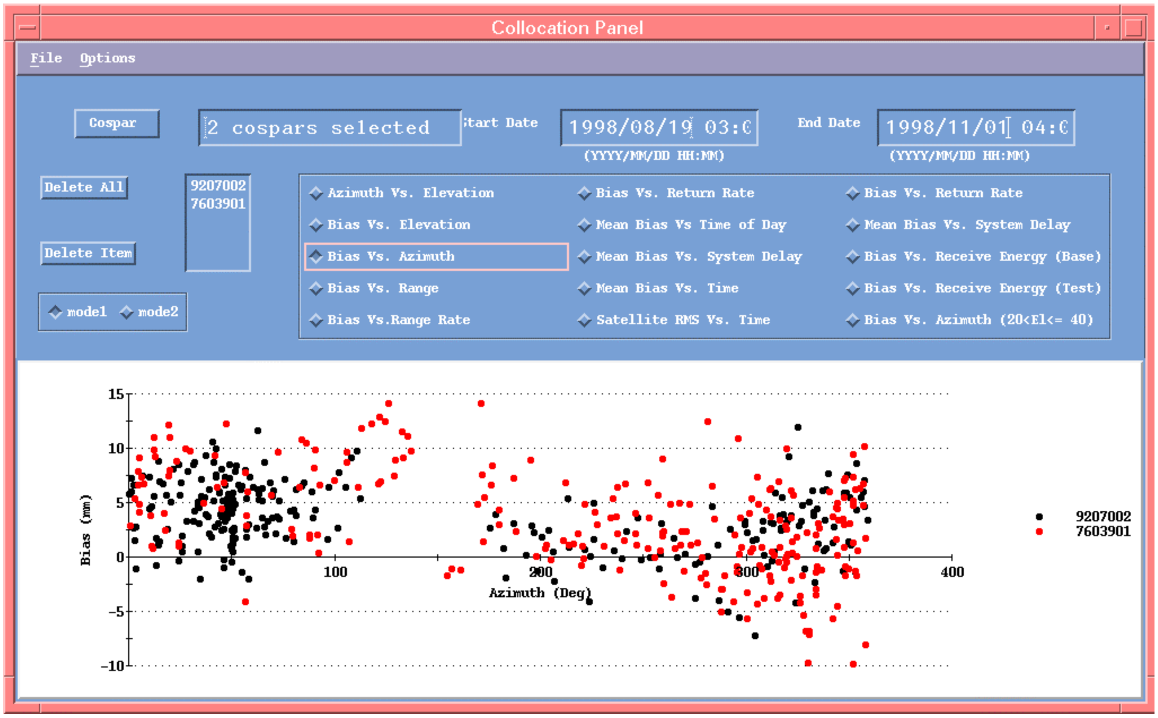


Figure 5: MLRO Collocation Analysis GUI Panel Screen Dump

Overall, the MLRO LAGEOS results showed an agreement with MOBLAS 7 of 3.5 mm with an approximate 3 mm RMS using all collocated normal points. The single shot scatter results for LAGEOS tracking varied depending on the atmospheric conditions. Under the worst atmospheric conditions, the single-shot scatter was between 5.0 mm and 6.0 mm RMS (typically 5.5 mm). In the fall, when the weather cleared, the MLRO routinely acquire LAGEOS satellites with a single-shot scatter of 4 mm RMS (varying between 3.8 mm and 4.2 mm RMS). It was clear that with a good atmosphere, the ASI can expect a typical LAGEOS-type pass to yield almost a 100% return rate with a single-shot RMS of about 4.0 mm. Since a normal point will contain almost 1200 points one might expect a normal point RMS to approach 0.1 mm.

The MLRO also performed collocation ranging using high-orbit (GLONASS, etc.) and low-orbit (Starlette, Stella, etc.) satellites. For GLONASS, the MLRO single-shot RMS varied between 4.5 mm (best) and 12 mm (worst) and typically about 8 mm RMS. This depends on the satellite's array orientation, which is a flat panel and can dramatically affect the single shot scatter. The mean bias with MOBLAS-7 for GLONASS satellites was 2.4 mm. For low-orbit satellites (Starlette, Stella, and ERS) the mean bias was about 2 mm and single shot scatter varied between 3.3 mm and 4.9 mm RMS.

In addition to the satellite tracking requirements, the MLRO also passed all of its other stringent collocation tests and completed collocation in October 1998. A much more detailed report showing all of the collocation data was provided to, reviewed, and approved by the ASI. The collocation data set was provided to the ASI for independent analysis. An interesting additional analysis by the ASI indicated that the data could be used to measure the spacecraft spin-rate. The ASI will present a separate paper describing these results in the future.

For the Future

A contract for a two-color ranging upgrade for the MLRO between the ASI and AlliedSignal was signed in November 1998. The engineering project to execute this upgrade is in progress. A separate paper in these proceedings describes the two-color plan.

The Matera facility construction began September 9, 1998 and is expected to be complete in March 1999. The Dome was constructed and accepted in March 1998 and delivered to Matera in early 1999.

Summary

The MLRO has performed exceptionally well, exceeding even its own very ambitious requirements. The system is already providing several interesting results (one of which was mentioned here) that could be used to further SLR technology. After a two-color upgrade it is expected to be in Matera in early 2000 in time for the next Laser Ranging Workshop.