Overview of the MLRO Project (History and Status)

G. Bianco, Agenzia Spaziale Italiana

M. Selden, T. Oldham, M. Bieneman, D. McClure, R. Sala, C. Steggerda, R. Stringfellow, M. Heinick, C. Clarke, H. Donovan, D. Patterson, J. Hundertmark, Honeywell Technology Solutions Inc.

The MLRO program, dreamed of by the Agenzia Spaziale Italiana and discussed in the 1980s, finally began in the last few days of 1993. A system that would not only contribute ranging data and analysis to the international community, but also provide a means to improve the SLR technology base. This was a considerable investment made by ASI, and with the incredible effort of our partner Honeywell and Telespazio, has paid off. Initial data results have been compared with the other international community members, and the results are very impressive. The objective was to develop a no-compromise multi and single (Lunar) photoelectron system that could also accommodate a two-color ranging upgrade and be designed to allow for enhanced automation. The goal of MLRO was a 3mm RMS system with a high satellite echo return rate. The actual system performs better much better than 3 mm RMS and has achieved return rates from LAGEOS approaching 100%. The MLRO has been a collaborative effort of system design reviews and testing that could not have succeeded without the contribution of many people in both Italy and the US.

The following is a narrative description of the history of the program. It highlights the basic system design features but not in great detail since this has already been discussed in previous congresses.

The MLRO system Design/Development/Integration has undergone essentially six basic phases. These are:

1. MLRO System Design Phase (Preliminary, Limited Critical and Critical Designs)

2. MLRO System Hardware Procurement/Fabrication and Software Module Development Phase

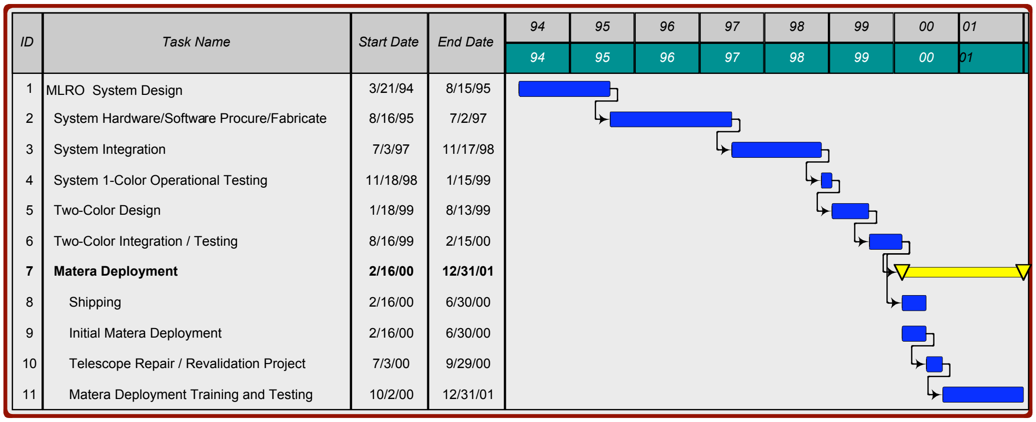
3. System Hardware and Software Integration/Application Phase (at GGAO)

4. GGAO Single-Color Satellite/Lunar ranging and Collocation Testing Phase

5. Two-Color Upgrade Design/Fabrication and preliminary testing phase.

6. Matera Deployment and Testing Phase (which has had several sub-phases).

A diagram showing the approximate phase timeframes is shown in figure 1.



ID	Task Name	Start Date	End Date
1	MLRO System Design	3/21/94	8/15/95
2	System Hardware/Software Procure/Fabricate	8/16/95	7/2/97
3	System Integration	7/3/97	11/17/98
4	System 1-Color Operational Testing	11/18/98	1/15/99
5	Two-Color Design	1/18/99	8/13/99
6	Two-Color Integration / Testing	8/16/99	2/15/00
7	**Matera Deployment**	**2/16/00**	**12/31/01**
8	Shipping	2/16/00	6/30/00
9	Initial Matera Deployment	2/16/00	6/30/00
10	Telescope Repair / Revalidation Project	7/3/00	9/29/00
11	Matera Deployment Training and Testing	10/2/00	12/31/01

Figure 1: Timeline for the MLRO Program

MLRO System Design Phase (1/1994 – 6/1995)

The initial design phase lasted 18-months and culminated in almost 20 volumes of fairly detailed design information. These were examined, criticised, and approved using three critical design reviews (CDR). The CDR documentation would also become the foundation for the system documentation. The design phase was done partially in parallel with the Fabrication of the telescope and of the MLRO laser subsystem.

MLRO System Fabrication Phase (6/1995 – 4/1997)

Most of these activities have been more-fully described in prior workshop proceedings, but are summarized here.

The MLRO design relied upon the custom construction of several electronic instruments, and subassemblies that would be integrated with commercial instruments to improve system performance. The main electronic instruments were the discriminator, event timer, range gate generator/simulator, and the peak amplitude measurement instrument. Each of these primary instruments went through a breadboard test phase.

The MLRO T/R Optics subsystem also required a significant investment of fabrication and in-process test time as the controlling system software allows for highly automated operation and control. The T/R optics subsystem was modelled using the Zemax CAD software and is made of very high-quality custom designed optical components. The entire mechanical structure was modeled in the ProEngineer and Zemax CAD system. Additionally, custom improvements were made to the telescope subsystem to improve target acquisition, system automation and diagnostics.

A new model MCP-PMT was specified and chosen to support the MLRO ranging requirements. This MCP-PMT was based on an existing commercial model, but the pulse shape and gain was specified to provide the pulse characteristics desired for improved ranging.

The MLRO software system is divided into three basic parts: the real-time control and data acquisition subsystem, the non-real-time data processing and analysis subsystem, and the X-Windows Graphical User Interface subsystem.

An entirely new object-oriented subsystem was developed for the real-time software. This was composed of class libraries and real-time infrastructure designs to allow for improved long-term maintenance.

The Non-real-time software system was based on the NASA data processing software, but reworked and tightly bound with an Oracle database table system for improved system flexibility and to allow for processing of multiple systems, assuming that the MLRO would be a part of a network. The MLRO incorporates an automated scheduling system, also tied into the Oracle structures and a Geodyne analysis capability. An infrastructure application was added to allow for monitoring of the NRT subsystem status.

All of the MLRO applications are controlled through the X-Windows interfaces and the system is constructed in a way to allow for a fully automated upgrade, if so desired. The X-Windows interface is primarily built on a set of custom object tools developed for the MLRO program. These make X-Windows application Fabrication easier, more stable and the process and behavior repeatable.

System Integration and Software Application Development (4/1997 – 9/1998)

The system integration began soon after the GGAO facility became ready in the spring of 1997. The system was quickly integrated and the first data results acquired in time for the 1997 WEGENER meeting in Maratea Italy. At first, the system used the initial versions of the custom instruments and software for control of the system. The system integration continued throughout 1997 and well into 1998. By the fall of 1998, the system successfully performed satellite and lunar ranging and was in its final data measurement configuration. The system underwent a successful formal collocation with MOBLAS-7. Preliminary results were presented half way through the collocation at the 1998 Workshop on Laser Ranging in Deggendorf, Germany. At that time a design for the two-color upgrade had been submitted to the ASI for consideration. In December 1998 this was approved.

During 1998 the MLRO facility also took its first form. The building was constructed with the help of the Basillicata regional government and the ASI procured the dome from Jackson Mississippi. Construction began in late 1998 and continued through most of 1999.

Two-Color Upgrade Phase (Jan to Nov, 1999)

The two-color upgrade phase was like a not-so-mini system Fabrication. A design phase culminated in a Critical Design Review and went forward into a fabrication phase through much of 1999. The two-color upgrade added an entirely separate optical and receiver subsystem for two-color versus one color (i.e. two green paths and one ultraviolet path). The two color subsystem included both dual MCP ranging and a separate streak camera ranging path, all highly automated and including significant diagnostics. The steak camera was made in Japan and a new special two-color T/R switch prism assembly was designed and made in the US.

The system ranging electronics were also upgraded to include the final versions of the discriminator, event timer, and RGG and peak detector. This upgrade not only improved overall system performance but added additional channels for control and input of the one and two color equipment.

A significant upgrade of the software system was also done, which dramatically increased the system capability but changed the software enough to introduce problems that would need to be worked-out later in Italy. The two -color systems was integrated at GGAO, but the size and configuration of the STALAS building did not allow for full testing of the upgrade and so after preliminary two-color testing was completed, the system was shipped to Italy, where the building would support the final testing of this upgrade. This need to move the system to its final facility for full testing extended the time needed in Italy, but resulted in an overall better program success.

Matera Deployment

The Matera deployment has been divided into four fundamental sub-phases. These are: 1) Shipping, 2) Initial (single-color) Deployment and testing, 3) Telescope Repair Project, 4) Deployment finalization: Two-Color set-up and Testing, Training, and Validation Testing.

Shipping

The first phase of the deployment did not go well. The shipping was routed differently than requested to the shipping company, which resulted in excessive handling of the telescope, which caused its damage. After delivery from Italian customs, the team began to install the system at Matera. Almost immediately it was noticed that there was a problem with the telescope: three of the primary support radial counterbalances (all on the same side) had become detached from the primary mirror that is the epoxy bonds had been broken. The team (HTSI, ASI, and telescope manufacturer) considered the options available at the time and elected to continue with the installation until the damage would no longer support the operational testing – first ensuring that no additional damage could occur from this.

Initial Installation and Testing

The initial installation, with the exception of the telescope, was relatively smooth and before long the system was able to range to ground targets and to satellites. Software problems that had been introduced during the two-color upgrade were gradually isolated and fixed. Before very long the system was able to range. Pointing instability caused by the telescope damage did not permit the system to perform ranging requiring precise pointing (Lunar Ranging). An initial data set was sent to the CSR for data confirmation and the results indicated that the system data measurement was working as before. By the end of June 2000, it was apparent from the pointing problem that further testing would require that the telescope be repaired.

Telescope Repair Project

At the time that the telescope damage was discovered a plan was developed to repair the damage. First, a set of criteria were established to determine which path the repair should take: If the mirror itself were damaged then the primary mirror cell would be removed and returned to Pittsburgh for replacement, if not it would be repaired in place. Special tools were manufactured to allow the repair and the strain gauges that are an integral part of the telescope would allow the system to be returned to factory specification.

In August / September 2000, a team arrived in Matera to repair the telescope damage. First the telescope was inspected to ensure that there was no damage to the glass surfaces, or any undiscovered cracks within the structure. After the repair a series of star calibrations, lunar tracking, and other tests confirmed that the telescope performance had been returned to it original specification.

Training, Two-Color Testing, Validation Testing

After the telescope repair the team returned to its work of installation, training, and testing. The software problems were gradually corrected to collocation timeframe stability and the system actually performs better now than during collocation both from an operational perspective and a data perspective. Due to the strain on the HTSI team from the first phases of deployment, the completion of the installation process has been focused into intense four-to-six week trips with a break between these to allow team members to be with their families. Two-color streak images were received in the spring of 2001 and since that time the team has been completing the operational documentation, performing the validation tests as weather permits and finalizing the training. During this period, the ASI team successfully operated the system on a non-interference basis and achieving very good results.

Summary

The MLRO program has actually been a collection of many projects. First a set of commercial procurement and custom fabrication projects, then a system integration, testing and collocation project. This followed by another (two-color) commercial procurement and HTSI fabrication project, system integration and initial testing project and a delivery and training program. Couple with these have been the coordinated efforts between ASI and HTSI personnel to orchestrate the overall flow of funding and the diverse technical efforts in both the US and Italy. It has been a successful collaborative effort between people from ASI, Telespazio, and Honeywell on a rather long and difficult journey, but all have benefited from and enjoyed the process.